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DEPARTMENT OF THE ARMY
UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36360

STEBG-TD (6) 1 JUN 67

SUBJECT: ~~Letter Report,~~ "Product Improvement Test, T53-L-11 Metal Spray Repaired Engine," ~~RDT&E Project No.~~ ____________, USATECOM Project No. 4-5-0151-13

(16) USATECOM-4-5-0151-13

TO: See Distribution

1. References.

a. Final Report of Test, USATECOM Project No. 4-3-0150-16, "Product Improvement Test (Comparative Evaluation) of the T53-L-11 Engine Inlet-Air Barrier Filter and Particle Separator," US Army Aviation Test Board, 15 June 1966.

b. Message, AMCPM-IR-T 48035, Commanding General, US Army Materiel Command, 23 November 1966, subject: "Request for Test Directive Product Improvement Test, T53 Axial Compressor Metal Spray Repaired Engine."

c. Iroquois Test Coordination Meeting, 6 December 1966.

d. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 14 December 1966, subject: "Test Directive, Product Improvement Test, T53-L-11 Metal Sprayed Repaired Engine."

e. Memorandum, STEBG-TP-A, US Army Aviation Test Board, 22 December 1966, subject: "Product Improvement Test, T53-L-11 Metal Sprayed Repaired Engine, USATECOM Project No. 4-5-0151-13."

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2. Background.

a. Many T53-L-11 engines returned to US Army Aeronautical Depot Maintenance Center (USAADMAC) for overhaul have the lands of the compressor cases severely eroded due to sand and dust ingestion. Until recently it was the costly practice to discard eroded cases. At present, eroded compressor cases are being repaired by a USAADMAC-developed and -approved metal-spray process and reinstalled on overhauled engines currently being sent to the Republic of Viet Nam (RVN).

b. The Iroquois Project Manager stated an urgent requirement to evaluate quickly the durability and the service life of the metal-spray repaired engine (reference 1c). On 14 December 1966, Headquarters, US Army Test and Evaluation Command (USATECOM), directed the US Army Aviation Test Board (USAAVNTBD) to conduct a product improvement test of the T53-L-11 metal-spray repaired engine (reference 1d).

3. Description of Materiel. The test item is a USAADMAC-overhauled T53-L-11 engine, S/N LE-09484, with the metal spray repair incorporated in the compressor housing.

4. Test Objective. To provide quantitative information on the durability and estimated service life of a metal-spray repaired T53-L-11 engine.

5. Method. The USAAVNTBD conducted the product improvement test of the metal-spray repaired engine during the period 8 December 1966 through 27 January 1967.

a. The test item was installed in UH-1D Helicopter, S/N 60-6034, and accumulated 174.5 flight hours (3.6 sand hours) with the test-bed helicopter operated at maximum gross weight (9,500 pounds). A total of 287 takeoffs and landings in sand/dust was made. The helicopter was not equipped with a sand/dust protective device.

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b. Engine performance data were collected at 25-flight-hour intervals. The top compressor case was removed at each 50-flight-hour interval to determine deterioration of the spray material and to insure flight safety. The test item was compared with T53-L-11 engine, S/N LE-10420, which was the unprotected baseline engine utilized during the Product Improvement Test, USATECOM Project Number 4-3-0150-16.

c. Testing was terminated on 27 January 1967 due to engine surge, and the test item was returned to USAADMAC for a test cell run and analytical inspection 2 February 1967. The erosion of the test item compressor housing was compared with the average T53 engine returned from RVN.

d. The condition and performance of the test item were reported to the sponsor (USAMC, Iroquois Project Manager) during the test period.

6. Summary of Results. The USAAVNTBD Engineering Analysis is attached as inclosure 1. The USAADMAC Inspection Report is attached as inclosure 2.

a. Performance.

(1) Some degradation in engine performance occurred during the test, but the performance remained within limits.

(2) At 174.5 engine operating hours, the pilot reported a suspected low power surge. The surge was confirmed after application of bias pressure to the fuel-control pressure sensor.

(3) Performance of the metal-spray repaired engine after 3.6 sand hours had not degraded to the extent of that of the baseline engine after 3.8 sand hours. The test engine surged only after application of bias pressure, while the baseline engine surged without application of pressure. However, sand concentration in the air appeared to be less than that to which the baseline engine was subjected.

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b. Erosion. Sand erosion damage to the metal-spray repaired axial compressor lands was more severe than that to the magnesium housing with HAE coating in the baseline engine.

7. Conclusions.

a. The metal-spray repaired axial compressor housing is not as durable as the standard magnesium housing with HAE coating.

b. In a severe operational environment (similar to that encountered during Air Assault I and II), the metal-spray repaired engine should have a service life of 200 hours.

8. Recommendation. It is recommended that the metal spray be considered a suitable interim repair for eroded lands of axial compressor housings of the T-53-L-11 engine.

Raymond E. Johnson

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as

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Colonel, Artillery
President

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ENGINEERING ANALYSIS

INCLOSURE 1

I. Introduction.

During test of the metal-spray repaired engine (S/N LE-09484), performance data were collected at 25-hour intervals. The top compressor case was removed at 50-hour intervals to allow a cursory inspection to insure flight safety. At 174.5 engine hours (3.6 sand hours), the pilot reported a low power surge. Efforts to duplicate the surge were unsuccessful. A surge was encountered, however, upon application of bias pressure to the fuel-control pressure sensor. On the basis of the above conditions relative to surge, the increased exhaust gas temperature (EGT) (figure 2 and paragraph IIIB3a), and the general condition of the second-stage compressor lands at the 3:00 to 4:30 position (figure 26), the test was terminated at 174.5 engine hours (3.6 sand hours) upon the recommendation of the project engineer.

II. Results.

A. Performance.

A graphic indication of the change of engine performance after 174.5 engine hours (3.6 sand hours) can be seen in figures 1, 2, 3, 4, and 5.

B. Visual and Dimensional.

1. The top case of the compressor was removed for inspection at 53.0 engine hours (1.5 sand hours). Only very minor erosion had occurred to the compressor blades and vanes. The general condition of the upper compressor case land areas is shown in figure 6 (left side, forward section), figure 7 (right side, forward section), figure 8 (left side, rear section), and figure 9 (right side, rear section). Figure 10 is a close-up photograph of the center section of the top case of the compressor at the second- and third-stage lands. Erosion, similar to that shown in figure 8, was evident on the leading edge of the third-stage land and to a minor degree on the second-stage land. The path of maximum erosion ran from the right forward portion of the upper compressor case counter-clockwise around to the left rear portion at the fourth-stage land. The erosion was not confined to this path alone, but was most highly concentrated along the described path.

2. The top compressor case was again removed and inspected at 113.0 engine hours (2.2 sand hours). The general condition of the

upper compressor case land areas is shown in figure 11 (left side, forward section), figure 12 (right side, forward section), figure 13 (left side, rear section), and figure 14 (right side, rear section). Figure 15 is a close-up of the area shown in figure 10. The almost total disappearance of the erosion pits (shown in figure 10) along the leading edge of the third-stage land is evident in figure 15. This was because the leading edge of the metal spray land had initially extended further into the airstream than had the outer vane shrouds. The sand eroded the leading edge of the land until the land was flush with the vane outer shroud. Figure 16 shows the pitting that was beginning to develop on the leading edge of the fifth-stage land at the right rear of the upper compressor case. Figure 17 shows the trailing edge of the fifth-stage stators on the upper compressor case at the left side. The thinning of the outer trailing edges of the vanes is evident. Figure 18 shows the similar condition on the right side of the upper compressor case at the trailing edge of the fifth-stage stators. The general condition of the vanes and blades is shown in figure 19.

3. The top compressor case was again removed and inspected at 161.2 engine hours (3.3 sand hours). The general condition of the top-half compressor lands is shown in figure 20 (left side, forward section), figure 21 (right side, forward section), figure 22 (left side, rear section), and figure 23 (right side, rear section). Figure 24 shows a center section of the third-, fourth-, and fifth-stage lands. Figure 25 shows the same area shown in figure 16. The pitting at the leading edge of the fifth-stage land had developed further. Figure 26 shows the general condition of the blades and vanes. Also observed at this inspection and pictured in figure 26 were erosion depressions (indicated by the arrow) in the lower compressor case aft of the second-stage stator vanes. The same area after 113.0 engine hours (2.2 sand hours) is indicated by the arrow in figure 19.

4. The engine was disassembled for inspection at USAADMAC after the test was terminated at 174.5 engine hours (3.6 sand hours). Figure 27 shows the general condition of the top case of the compressor. Inspection of the lower half of the compressor case revealed that it sustained far greater erosion damage than did the top half of the case. The condition of the lower half of the compressor case is shown in figure 28 (left side, forward section), figure 29 (right side, forward section), figure 30 (left side, rear section), and figure 31 (right side, rear section). The condition of the centrifugal impeller housing is shown in figures 32 and 33. The general condition of the rotor assembly is shown in figure

34. Some foreign object damage was evident, and the trailing edges of the blades at the outboard end were thinned and twisted up toward the convex side of the blade.

5. The gas-producer turbine-wheel tip clearances were:

Position	12:00	1:30	3:00	4:30	6:00	7:30	9:00	11:30
Clearance (inch)	0.034	0.039	0.039	0.035	0.041	0.034	0.042	0.042

III. Analysis.

A. Introduction.

The metal-spray repaired engine (S/N LE-09484) was compared with another T53-L-11 engine (S/N LE-10420), which was the unprotected baseline engine utilized during the "Product Improvement Test (Comparative Evaluation) of the T53-L-11 Engine Inlet-Air Barrier Filter and Particle Separator," USATECOM Project Number 4-3-0150-16. Direct comparison of the two engines was impossible because of the lack of pre-test dimensional data on the metal-spray repaired engine and the different environments in which each was tested.

B. Performance.

Test cell calibration data for both engines were used in the following comparisons, except where noted:

1. Referred Shaft Horsepower.

a. Metal-Spray Repaired Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Referred Shaft Horsepower, 0.0 Sand Hour	595	790	1005
Referred Shaft Horsepower, 3.6 Sand Hours	570	745	940
Decrease	25	45	65
Decrease (percent)	4.2	5.7	6.5

b. Baseline Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Referred Shaft Horsepower, 0.0 Sand Hour	545	728	919
Referred Shaft Horsepower, 3.8 Sand Hours	535	700	880
Decrease	10	28	39
Decrease (percent)	1.8	3.9	4.3

2. Referred Fuel Flow

a. Metal-Spray Repaired Engine.

No identifiable change in fuel flow had occurred after 3.6 sand hours.

b. Baseline Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Referred Fuel Flow (lb./hr.), 0.0 Sand Hour	442	523	611
Referred Fuel Flow (lb./hr.), 3.8 Sand Hours	470	550	639
Increase (lb./hr.)	28	27	28
Increase (percent)	6.3	5.2	4.6

3. Referred Exhaust Gas Temperature.

a. Metal-Spray Repaired Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Referred Exhaust Gas Temperature (°C.), 0.0 Sand Hour	510	540	581
Referred Exhaust Gas Temperature (°C.), 3.6 Sand Hours	532	562	600
Increase (°C.)	22	22	19
Increase (percent)	4.3	4.1	3.3

b. Baseline Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Referred Exhaust Gas Temperature (°C.), 0.0 Sand Hour	463	489	524
Referred Exhaust Gas Temperature (°C.), 3.8 Sand Hours	498	525	552
Increase (°C.)	35	36	28
Increase (percent)	7.6	7.4	5.4

4. Compressor Pressure Ratio.

a. Metal-Spray Repaired Engine.

Compressor out-pressure was not recorded in the test cell. The following data are based on aircraft instrumentation.

Referred Gas-Producer Speed (percent)	86	90	94
Compressor Pressure Ratio, 0.0 Sand Hour	4.39	4.93	5.55
Compressor Pressure Ratio, 3.6 Sand Hours	4.25	4.77	5.35
Decrease	0.14	0.16	0.20
Decrease (percent)	3.2	3.3	3.6

b. Baseline Engine.

Referred Gas-Producer Speed (percent)	86	90	94
Compressor Pressure Ratio, 0.0 Sand Hour	4.66	5.20	5.74
Compressor Pressure Ratio, 3.8 Sand Hours	4.53	5.01	5.51
Decrease	0.13	0.19	0.23
Decrease (percent)	2.8	3.7	4.0

5. Specific Fuel Consumption.

a. Metal-Spray Repaired Engine.

Referred Shaft Horsepower	500	700	900
Specific Fuel Consumption, 0.0 Sand Hour	0.900	0.752	0.687
Specific Fuel Consumption, 3.6 Sand Hours	0.955	0.798	0.720
Increase	0.055	0.046	0.033
Increase (percent)	6.1	6.1	4.8

b. Baseline Engine.

Referred Shaft Horsepower	500	700	900
Specific Fuel Consumption, 0.0 Sand Hour	0.841	0.730	0.671
Specific Fuel Consumption, 3.8 Sand Hours	0.900	0.784	0.720
Increase	0.059	0.054	0.049
Increase (percent)	7.0	7.4	7.3

C. Visual and Dimensional.

1. The general condition of the axial and centrifugal compressor housing of the baseline engine (S/N LE-10420) after 3.8 hours of sand exposure is shown in Figures 35 and 36. It would appear that the erosion of the axial compressor land areas of the metal-spray repaired engine (S/N LE-09484) after 3.6 hours of sand exposure is more severe than the erosion of the land areas of the baseline engine. Comparison of the trailing edge outboard blade tips of the axial compressor blades, however, indicated the blade tips on the baseline engine (S/N LE-10420) had eroded to a rounded-off condition (Figure 37). The trailing-edge outboard blade tips of the metal-spray repaired engine were thinning and rolling up toward the convex side (Figure 34), but had not eroded away like those in the baseline engine.

2. Another parameter used to analyze the erosive effect to the two engines was a comparison of the gas-producer turbine-wheel tip clearances. The tip clearances for the baseline engine after 3.8 hours of sand exposure were:

Position	12:00	1:30	3:00	4:30	6:00	7:30	9:00	11:30
Clearance (inch)	0.037	0.037	0.035	0.038	0.045	0.043	0.041	0.041

Average Tip Clearance = 0.040 inch

The tip clearances for the metal-spray repaired engine after 3.6 hours of sand exposure were:

Position	12:00	1:30	3:00	4:30	6:00	7:30	9:00	11:30
Clearance (inch)	0.034	0.039	0.039	0.035	0.041	0.034	0.042	0.042

Average Tip Clearance = 0.038 inch

No initial tip clearances were available for the metal-spray repaired engine; therefore, further analysis relative to the tip clearances was not possible. It appears, however, that less sand erosion had occurred to the gas-producer section of the metal-spray repaired engine than to that of the baseline engine.

3. The baseline engine surged without application of bias pressure after 3.8 hours of sand exposure. Surge was confirmed on the metal-spray repaired engine after 3.6 hours of sand exposure only after application of 2.5 p.s.i. bias pressure to the fuel-control pressure sensor. The engine was cleaned, and surge could then be induced only after application of 3.5 p.s.i. to the pressure sensor.

D. General.

The performance of the metal-spray repaired engine (S/N LE-09484) had not degraded in 3.6 sand hours to the extent of that of the baseline engine (S/N LE-10420) after 3.8 sand hours. The metal-spray repaired engine would not surge without application of bias pressure to the fuel-control pressure sensor after 3.6 sand hours. The baseline engine surged without bias pressure being applied to the fuel control pressure sensor after 3.8 sand hours. The gas-producer turbine-wheel average tip clearance was less in the metal-spray repaired engine after 3.6 sand hours than the clearance in the baseline engine after 3.8 sand

hours. The axial compressor blades in the metal-spray repaired engine had incurred less erosion damage after 3.6 sand hours than had the blades in the baseline engine after 3.8 sand hours. Although the sand concentration was not determined in the test of the metal-spray repaired engine, it appeared to be less than that to which the baseline engine was subjected (0.003 grams/ft^3). Sand erosion damage to the metal-spray repaired axial compressor lands was, however, more severe than that in the baseline engine with the magnesium housing and HAE coating.

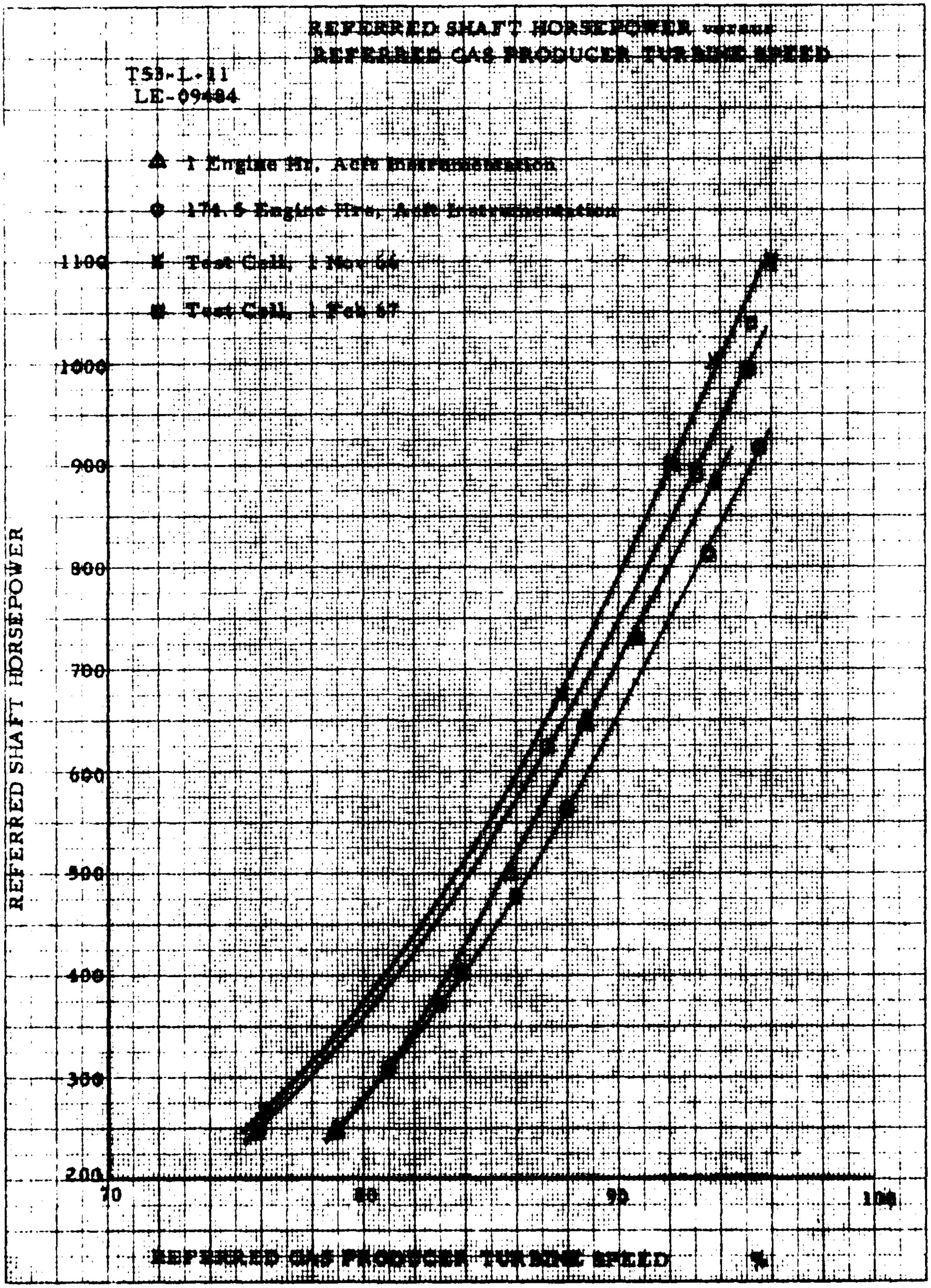

REFERRED SHAFT HORSEPOWER
T53-L-11
REFERRED SHAFT HORSEPOWER
1100
1000
900
800
700
600
500
400
300
200
70
80
90
100
%

Figure 1.

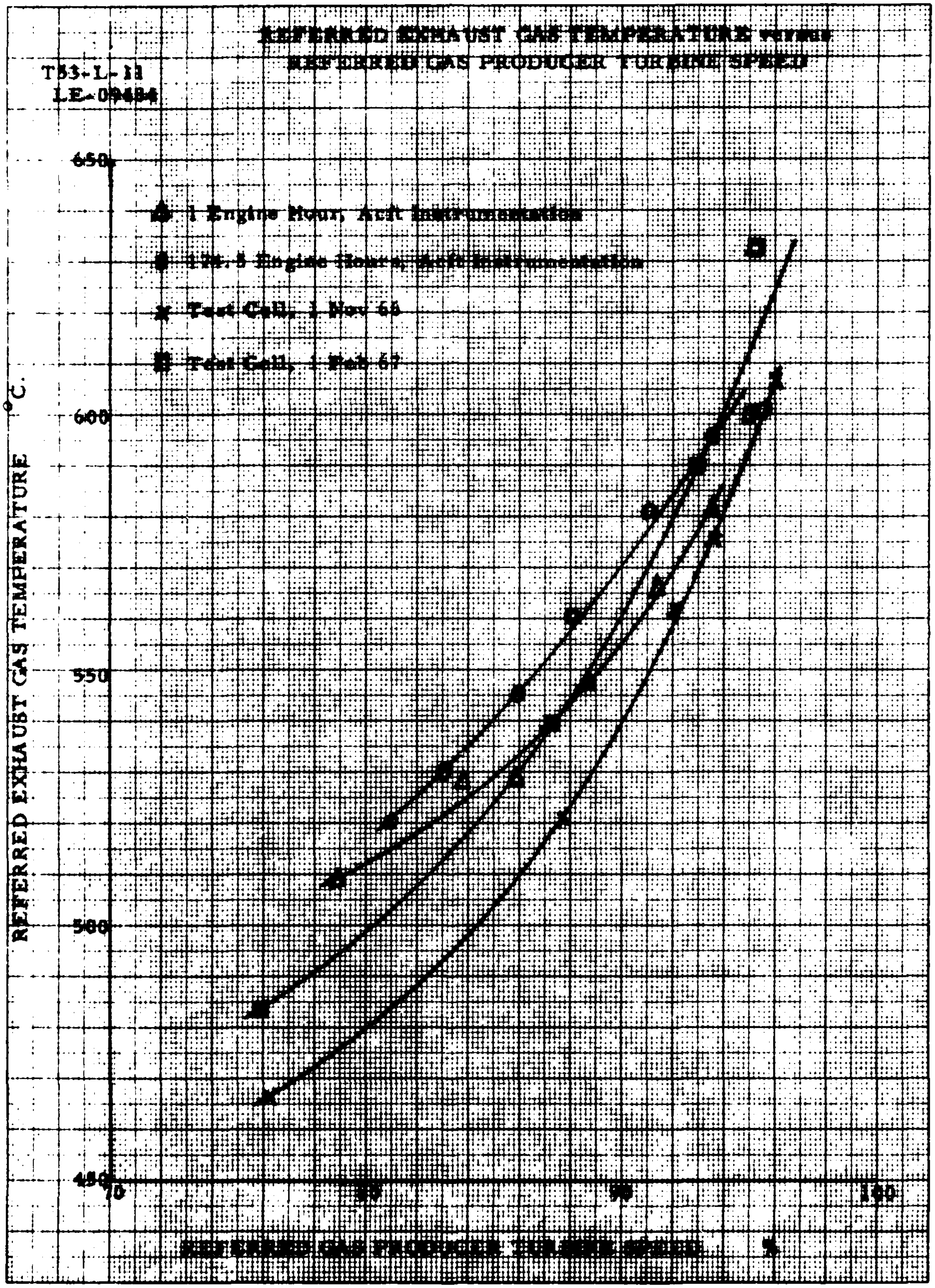

REFERRED EXHAUST GAS TEMPERATURE versus
REFERRED GAS PRODUCER TURBINE SPEED
T53-L-11
LE-09484
1 Engine Hour, Acft Instrumentation
124.5 Engine Hours, Acft Instrumentation
Test Cell, 1 Nov 66
Test Cell, 1 Feb 67
REFERRED EXHAUST GAS TEMPERATURE °C.
650
600
550
500
450
70
80
90
100
REFERRED GAS PRODUCER TURBINE SPEED %

Figure 2.

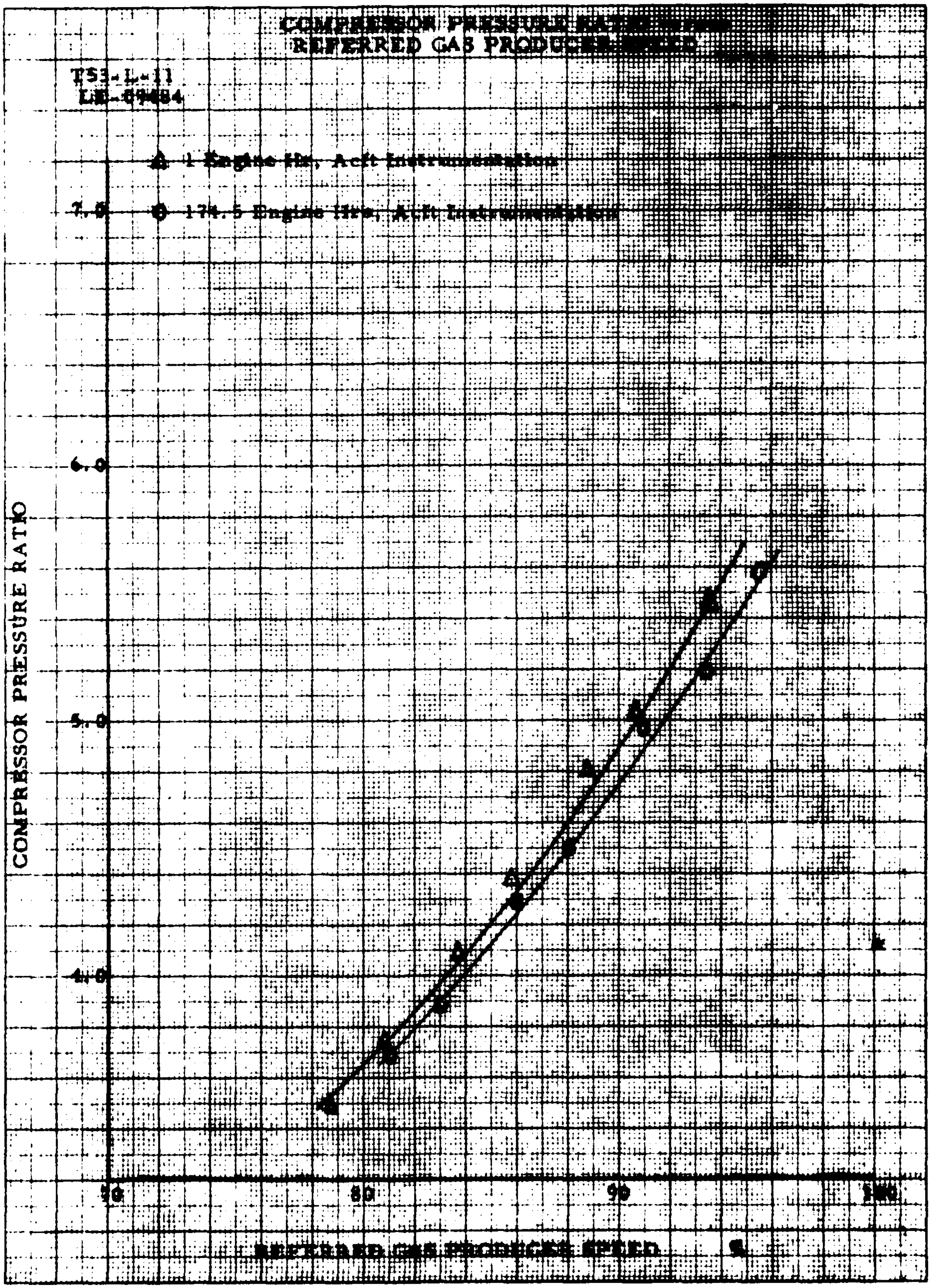

T53-L-11
1 Engine Hr, Acft Instrumentation
174.5 Engine Hrs, Acft Instrumentation
7.0
6.0
5.0
4.0
COMPRESSOR PRESSURE RATIO
80
90

Figure 3.

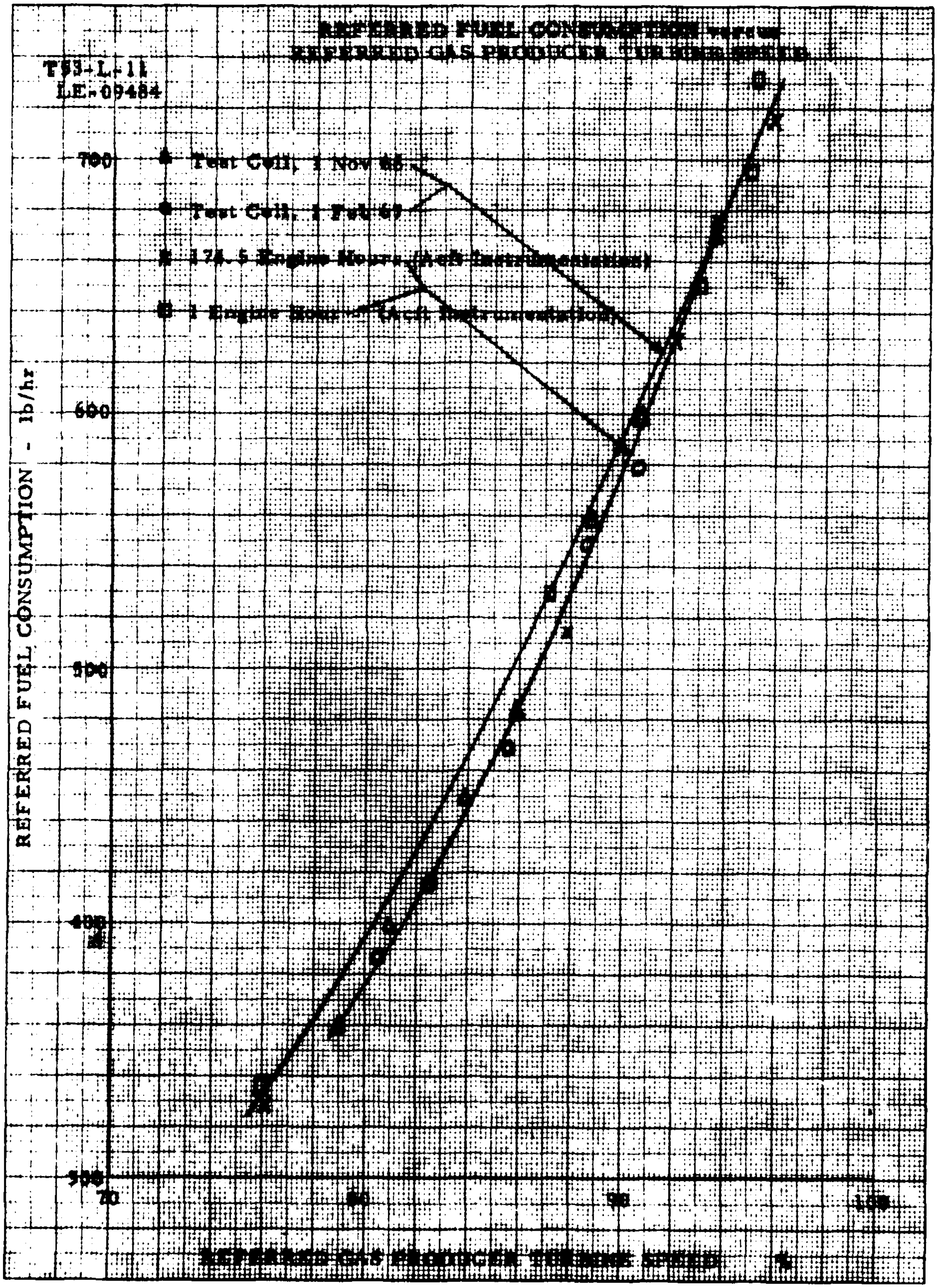

T53-L-11
LE-09484
Test Cell, 1 Nov 66
Test Cell, 1 Feb 67
REFERRED FUEL CONSUMPTION - lb/hr
700
600
500
400
300
70
80
90
100

Figure 4.

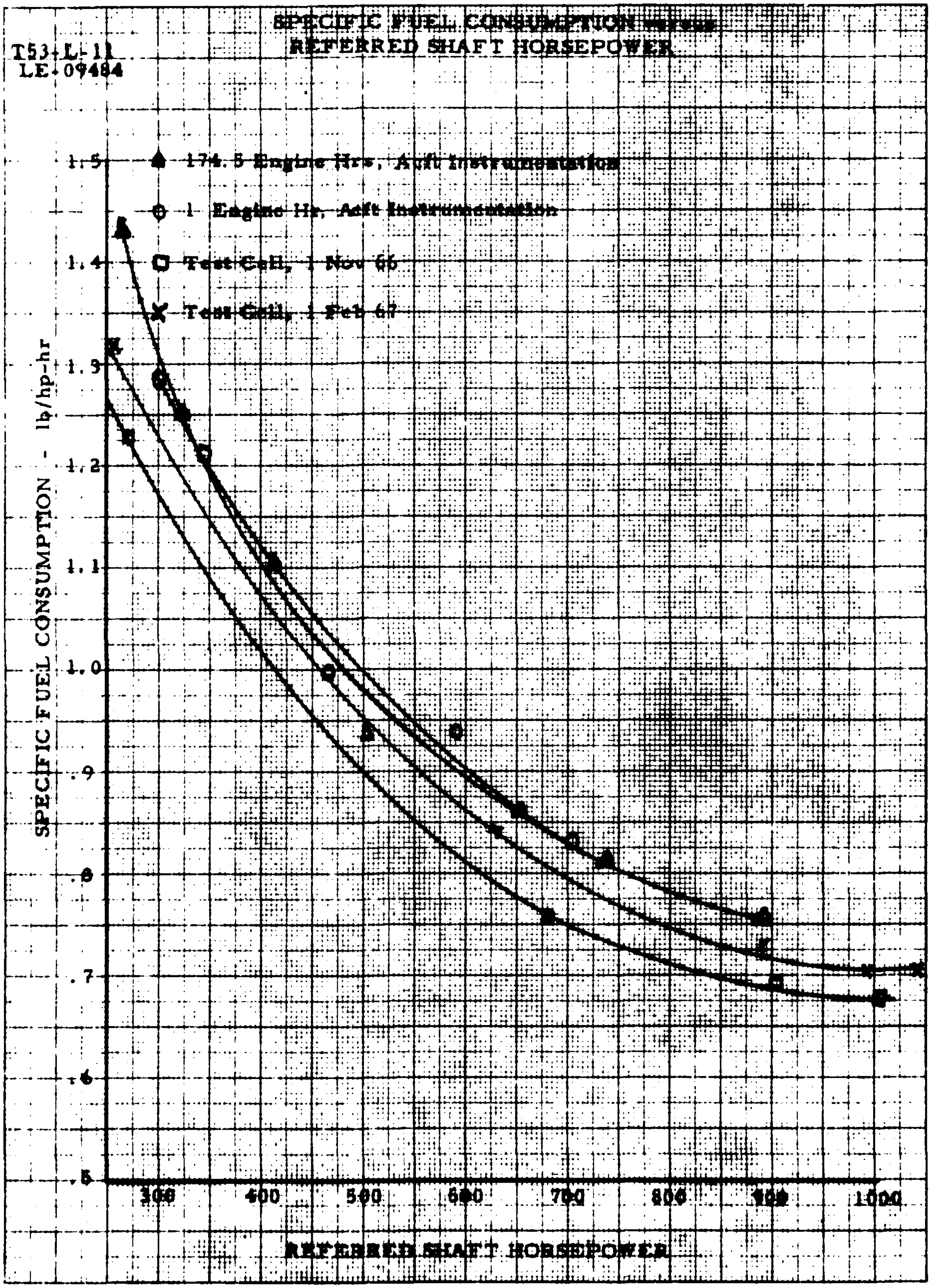

SPECIFIC FUEL CONSUMPTION versus
REFERRED SHAFT HORSEPOWER
T53-L-11
LE-09484
174.5 Engine Hrs, Aft Instrumentation
1 Engine Hr, Aft Instrumentation
Test Cell, 1 Nov 66
Test Cell, 1 Feb 67
SPECIFIC FUEL CONSUMPTION - lb/hp-hr
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
300
400
500
600
700
800
900
1000
REFERRED SHAFT HORSEPOWER

Figure 5.

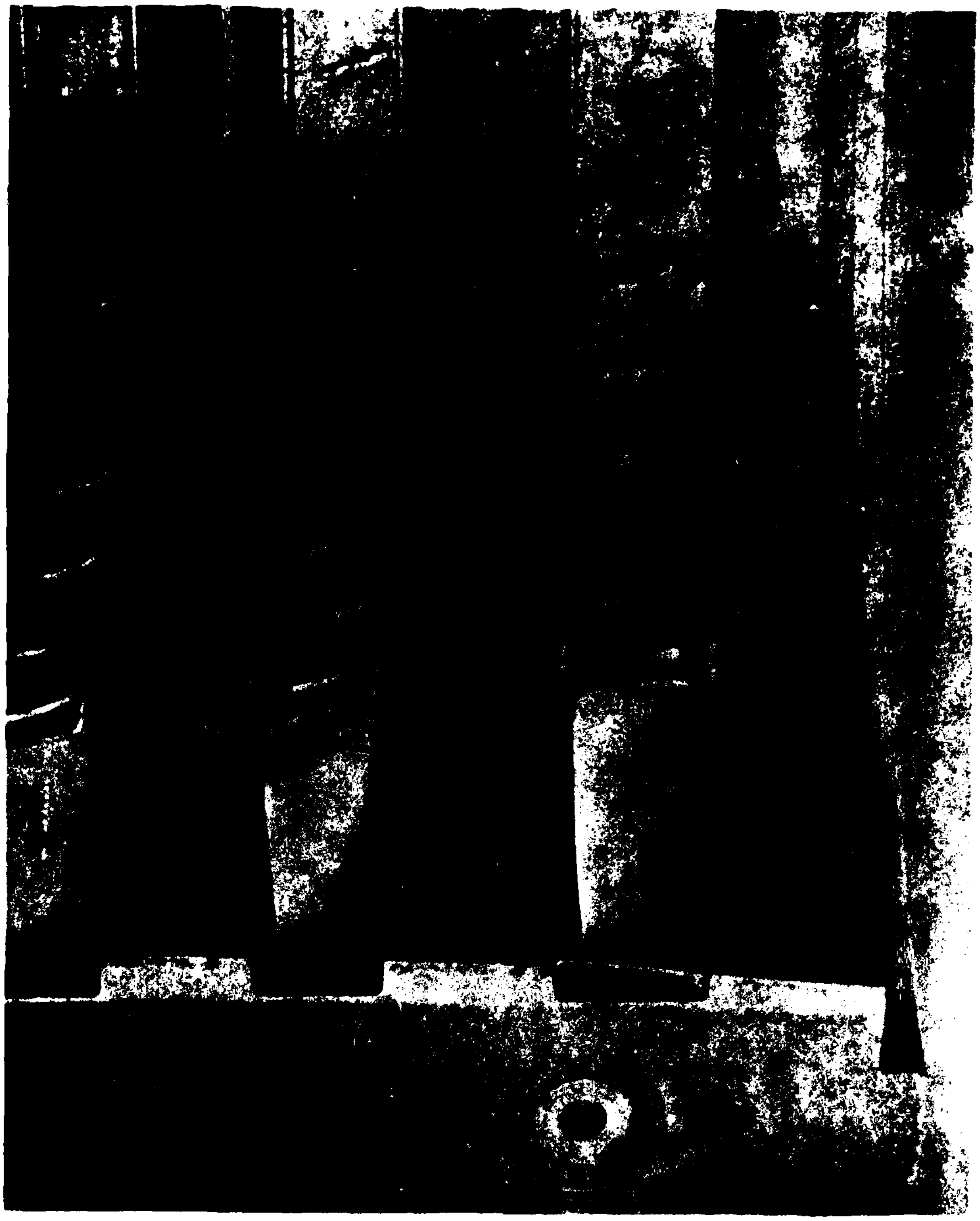


Figure 6.

Figure 7.

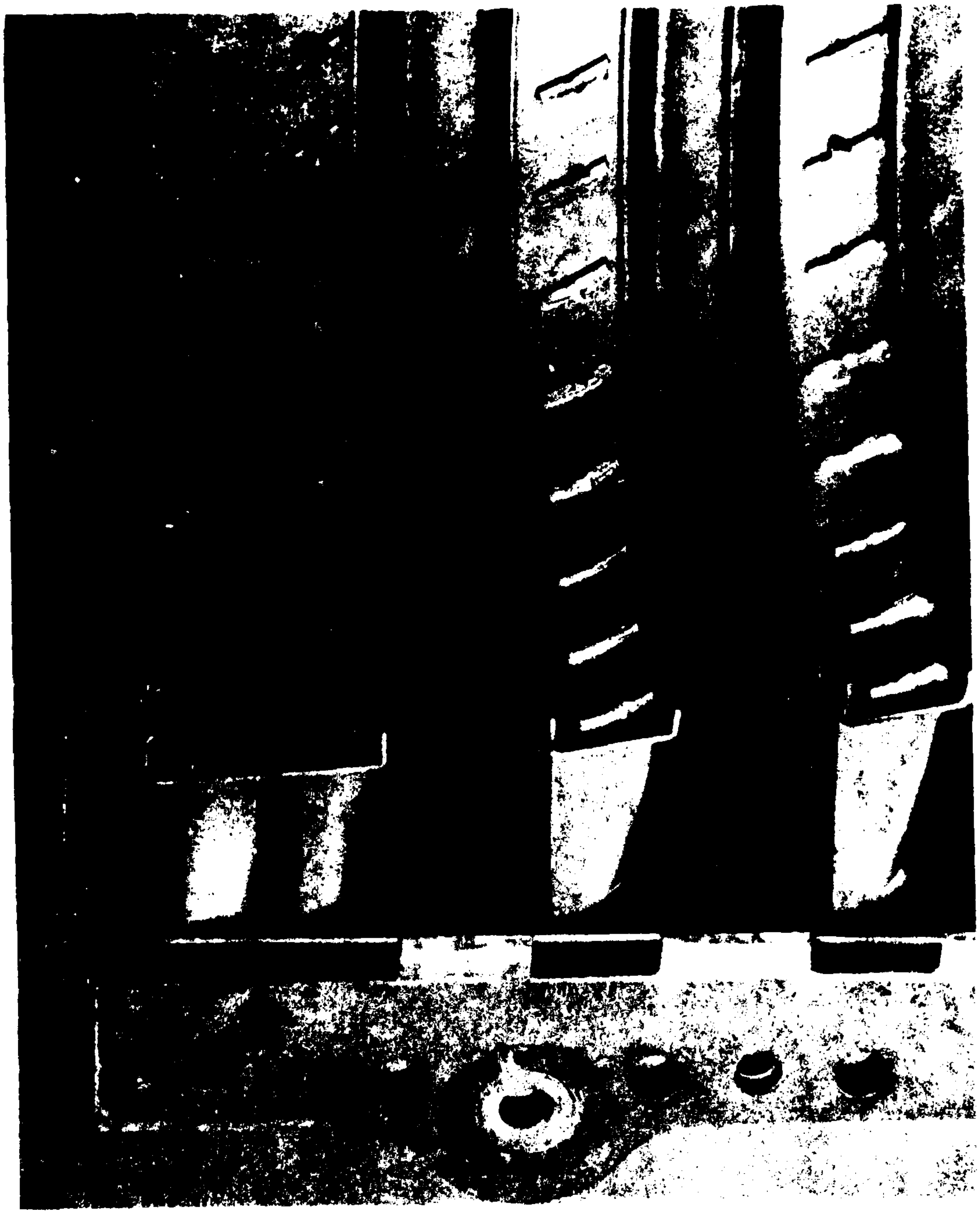


Figure 8.

Figure 9.

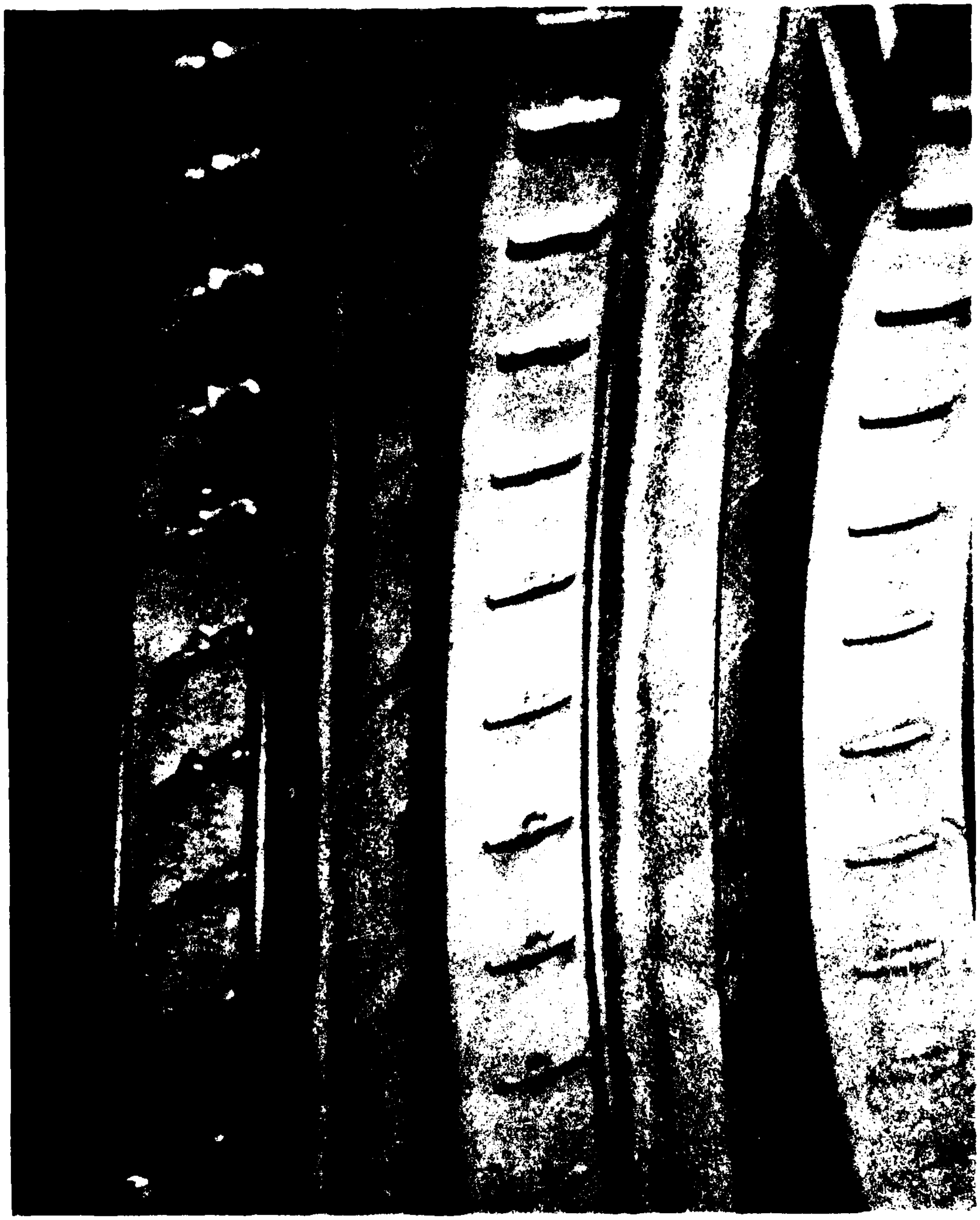
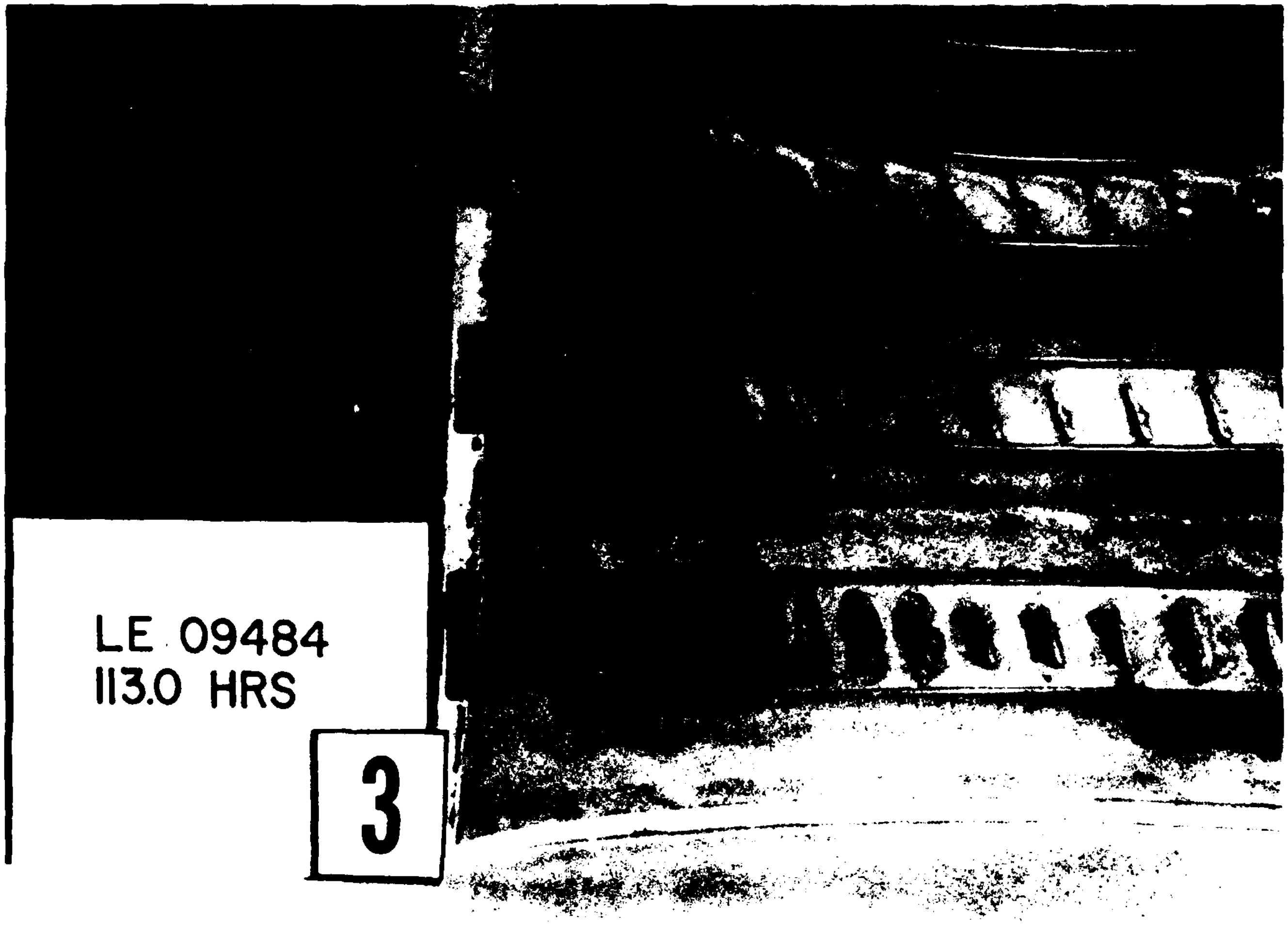


Figure 10.



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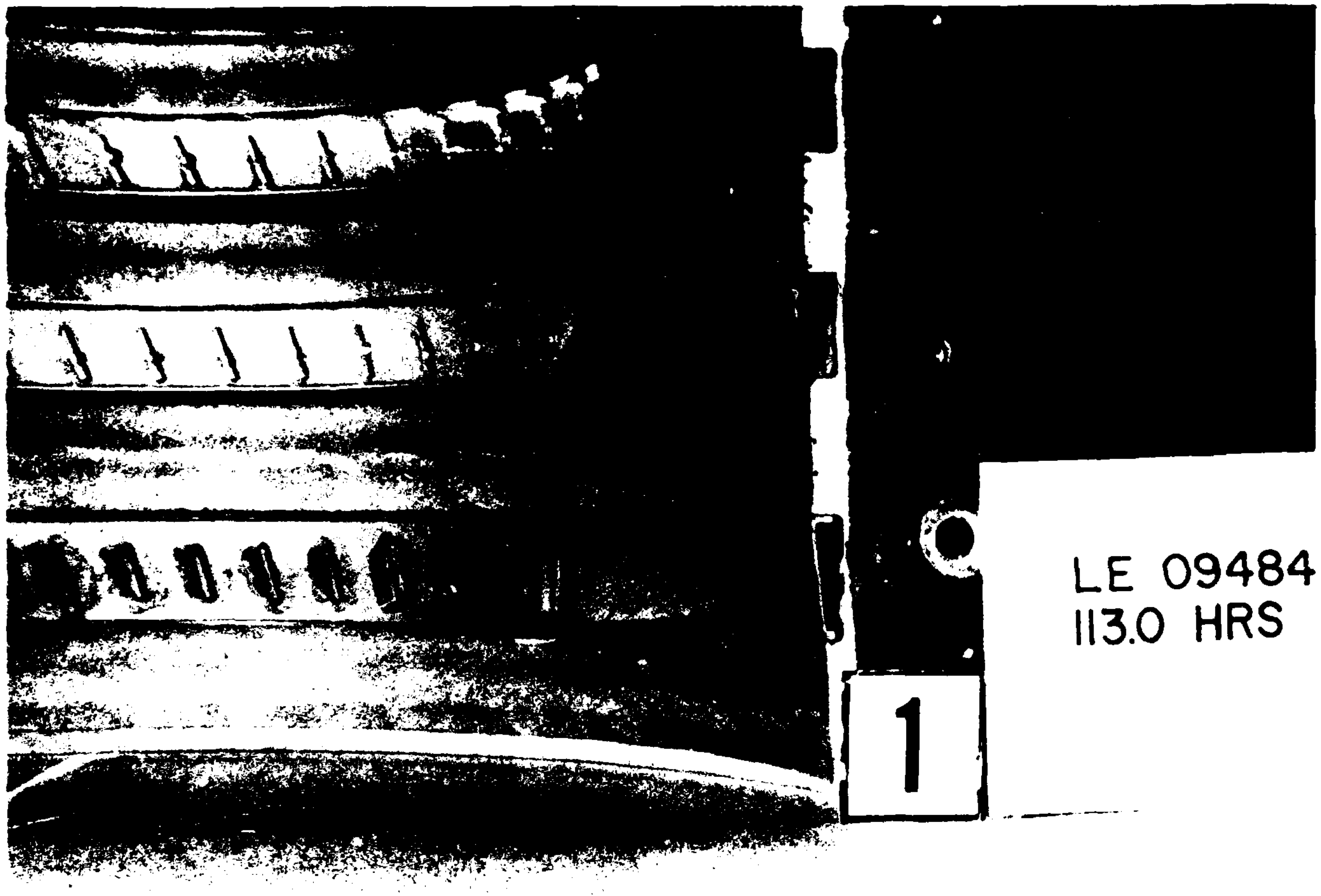

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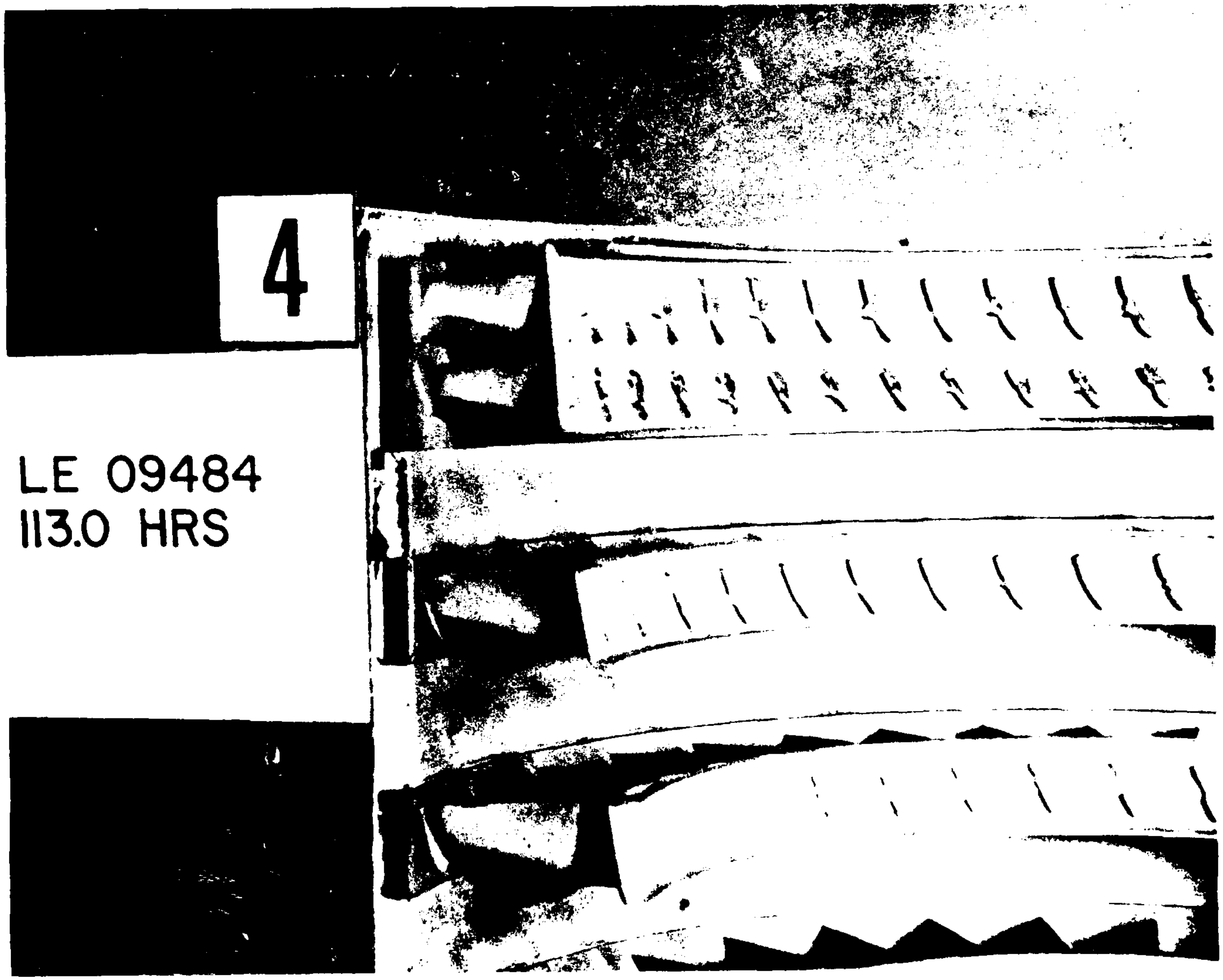

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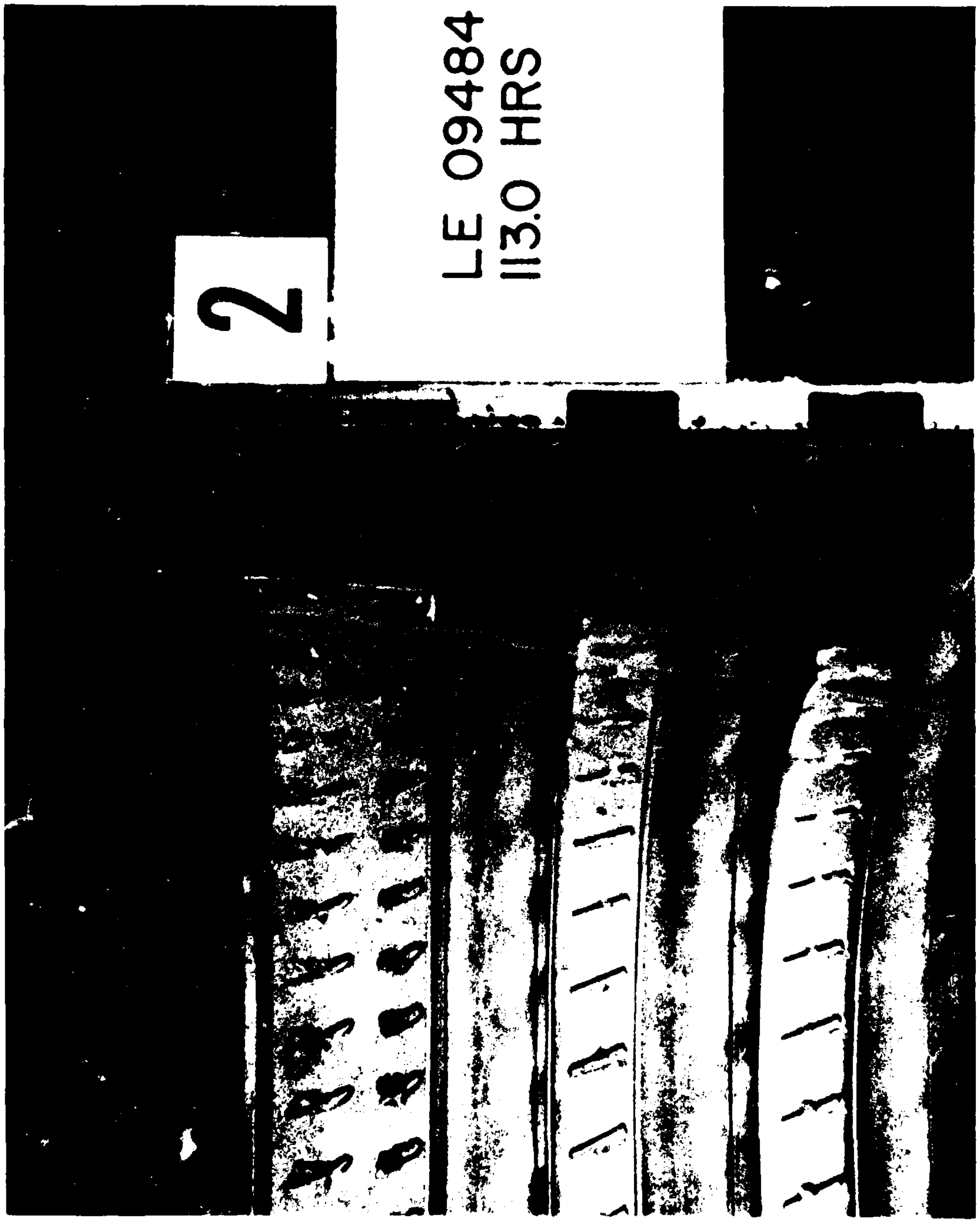


Figure 14.

Figure 1[illegible]

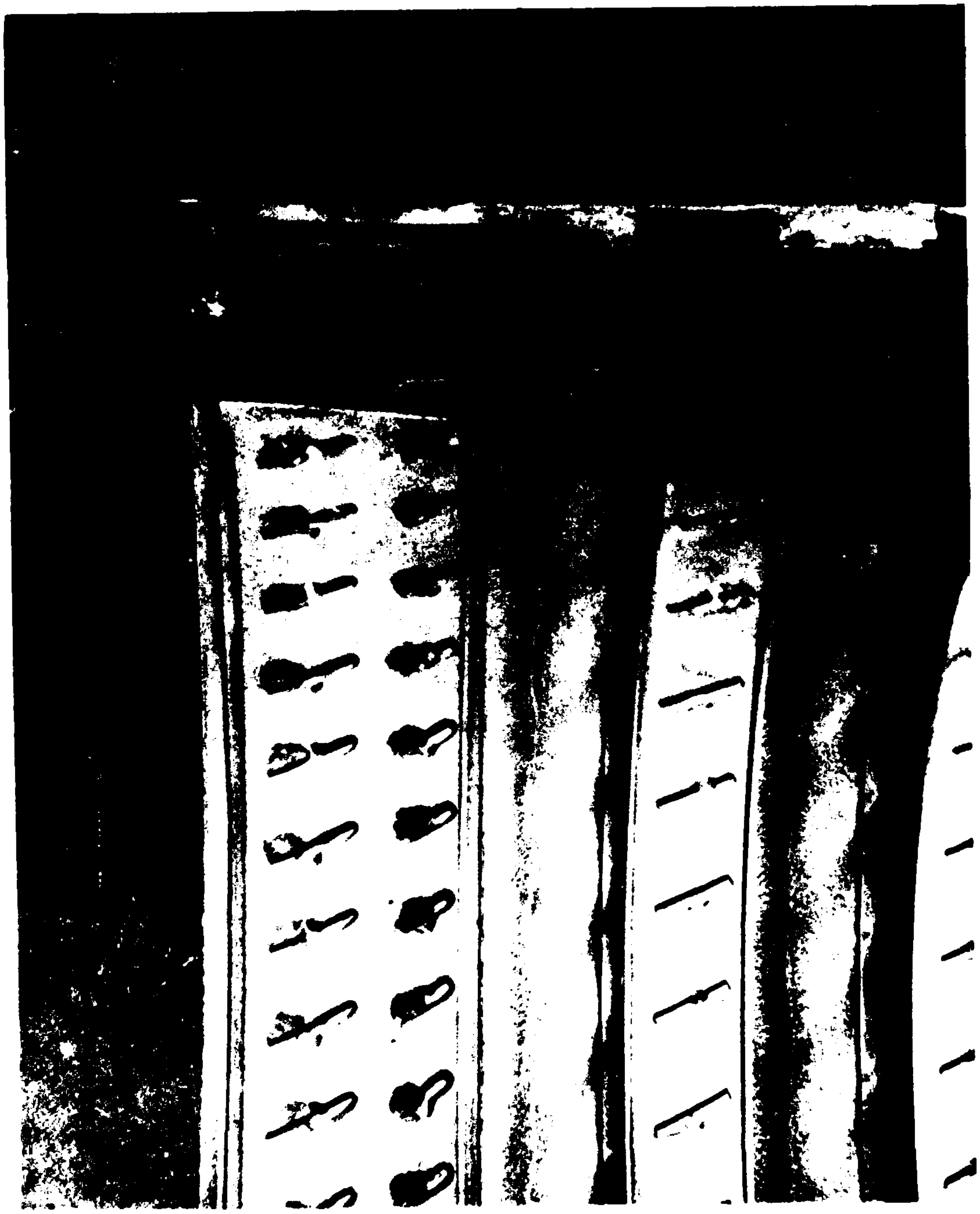


Figure 1b.

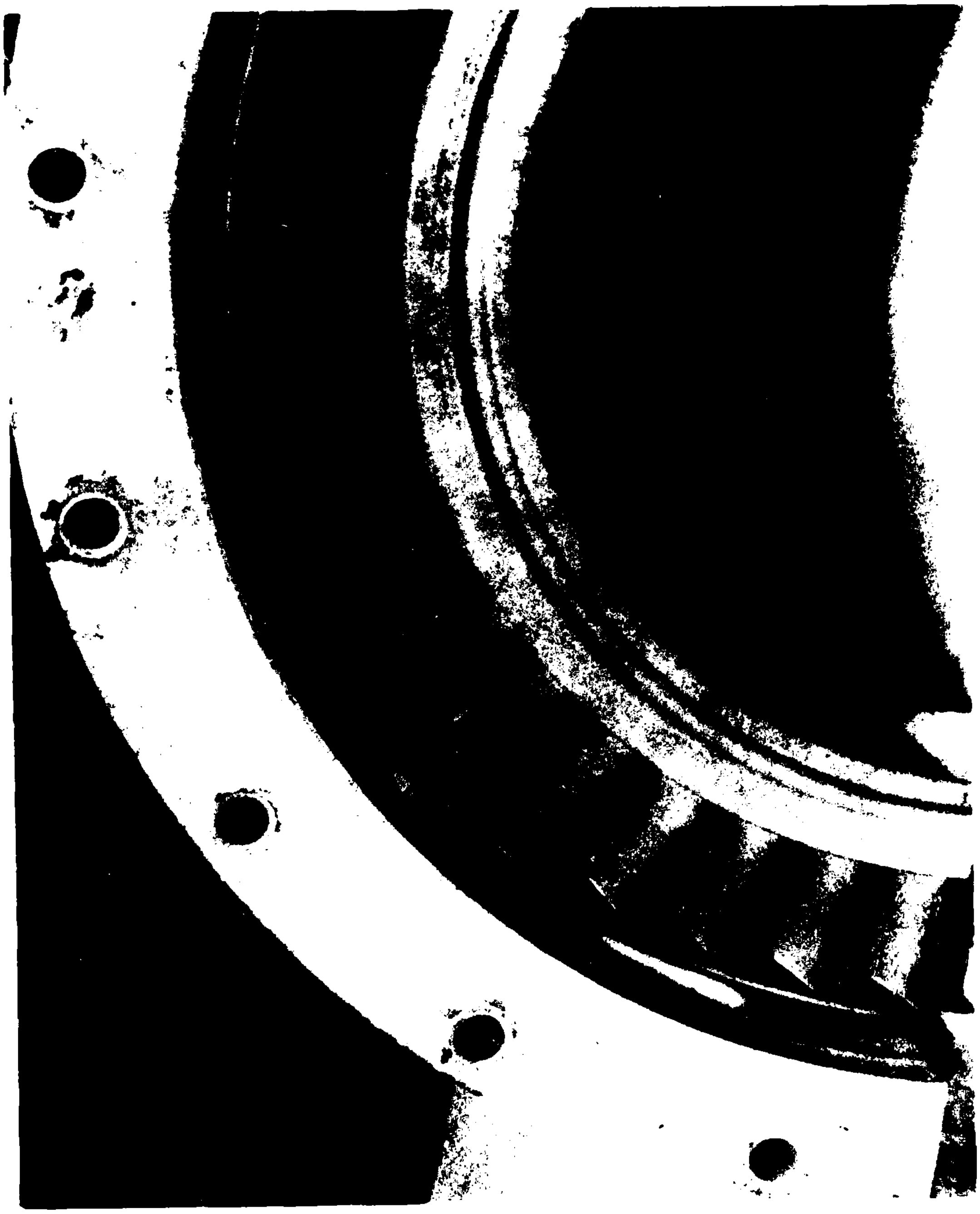


Figure 17.

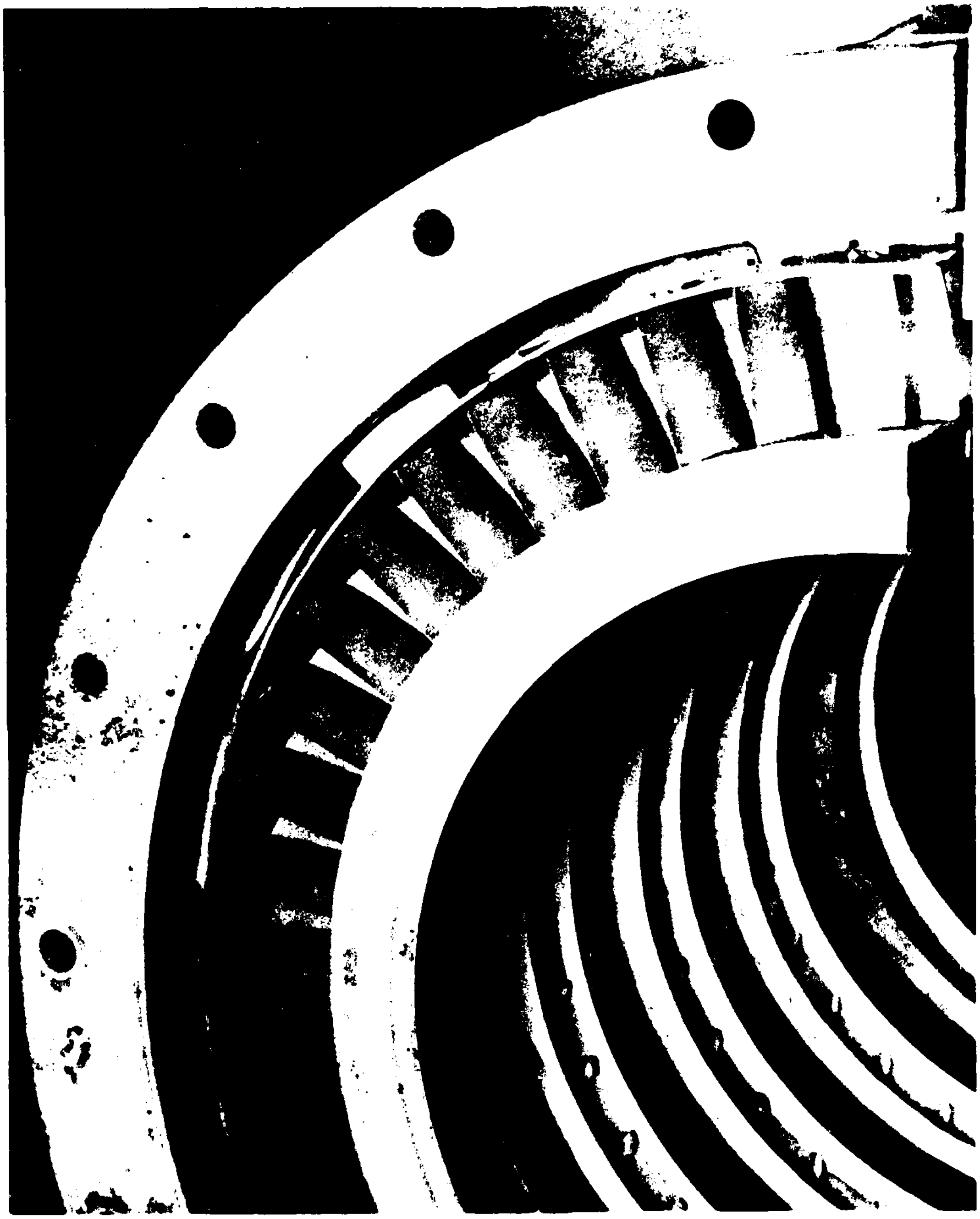


Figure 18.

Figure 19.

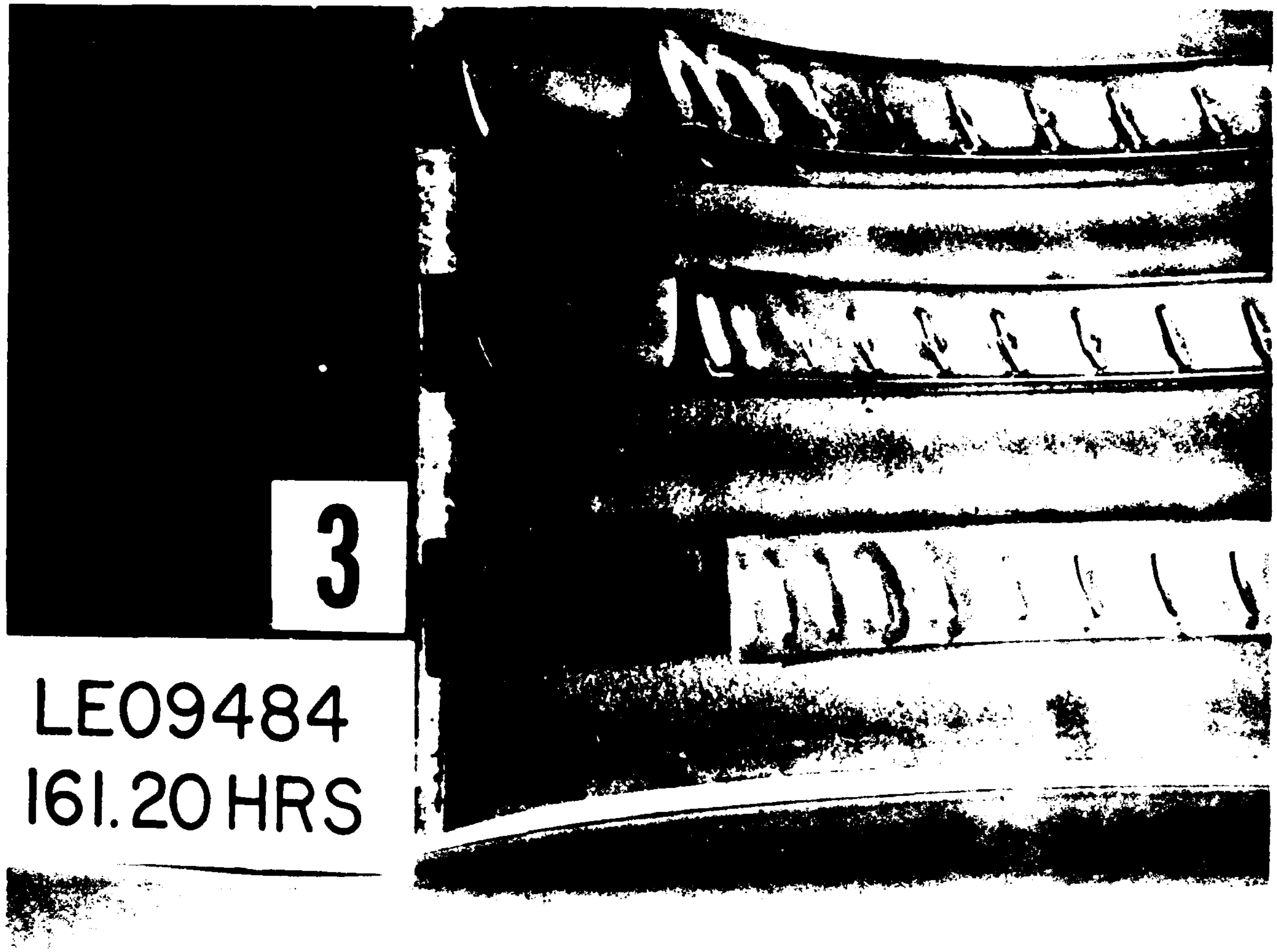


Figure 20.

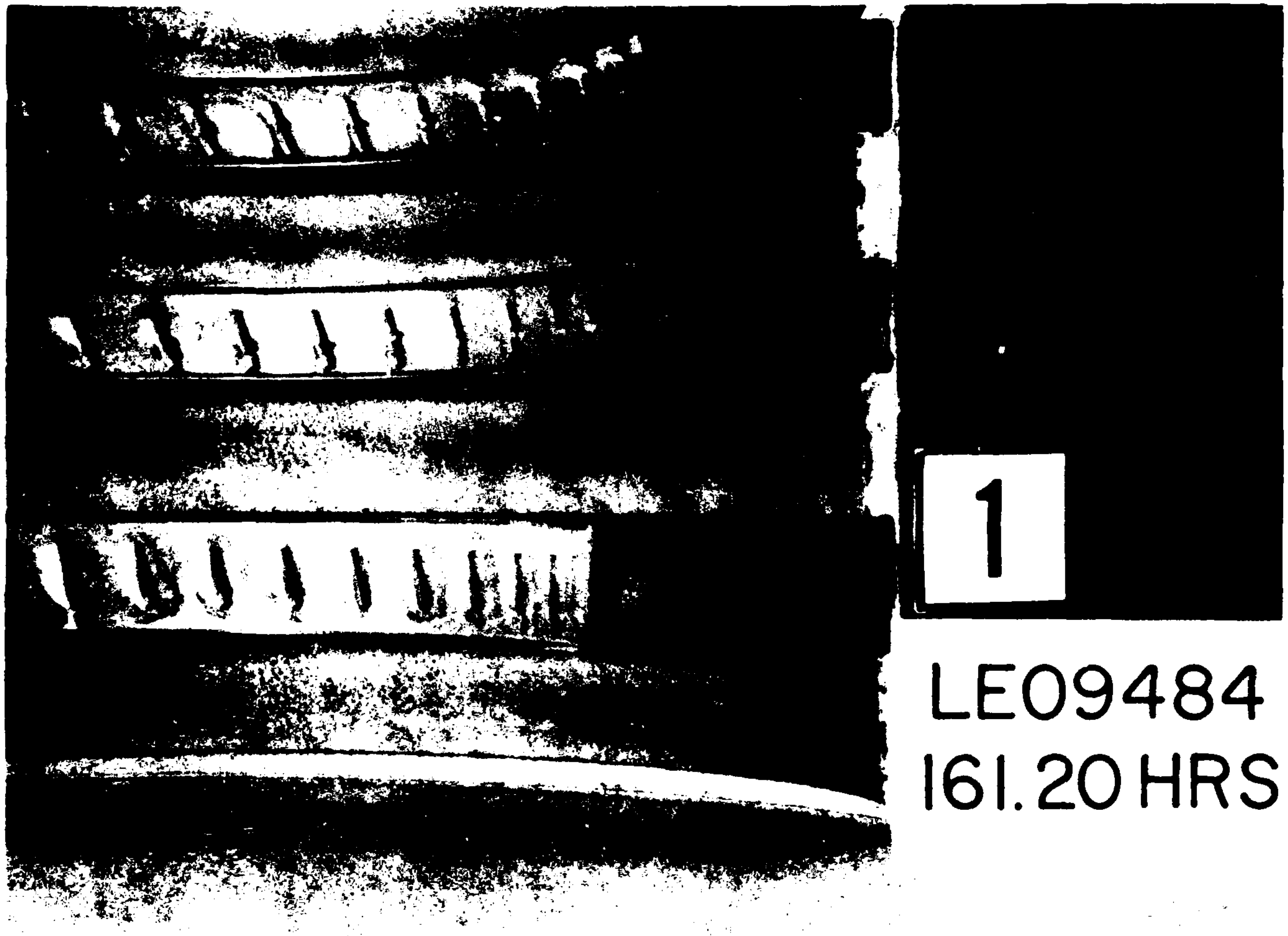
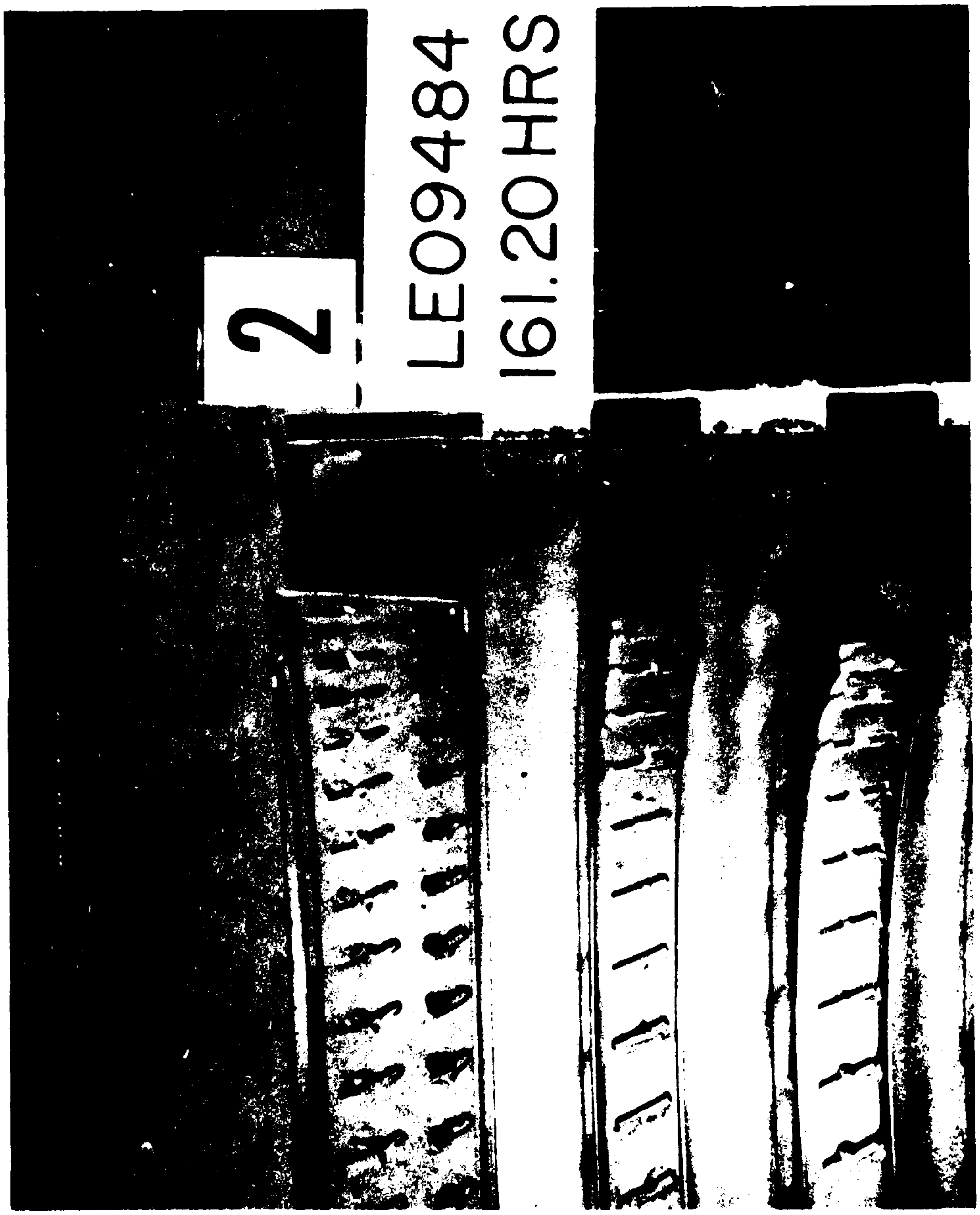


Figure 21.

Figure 22.



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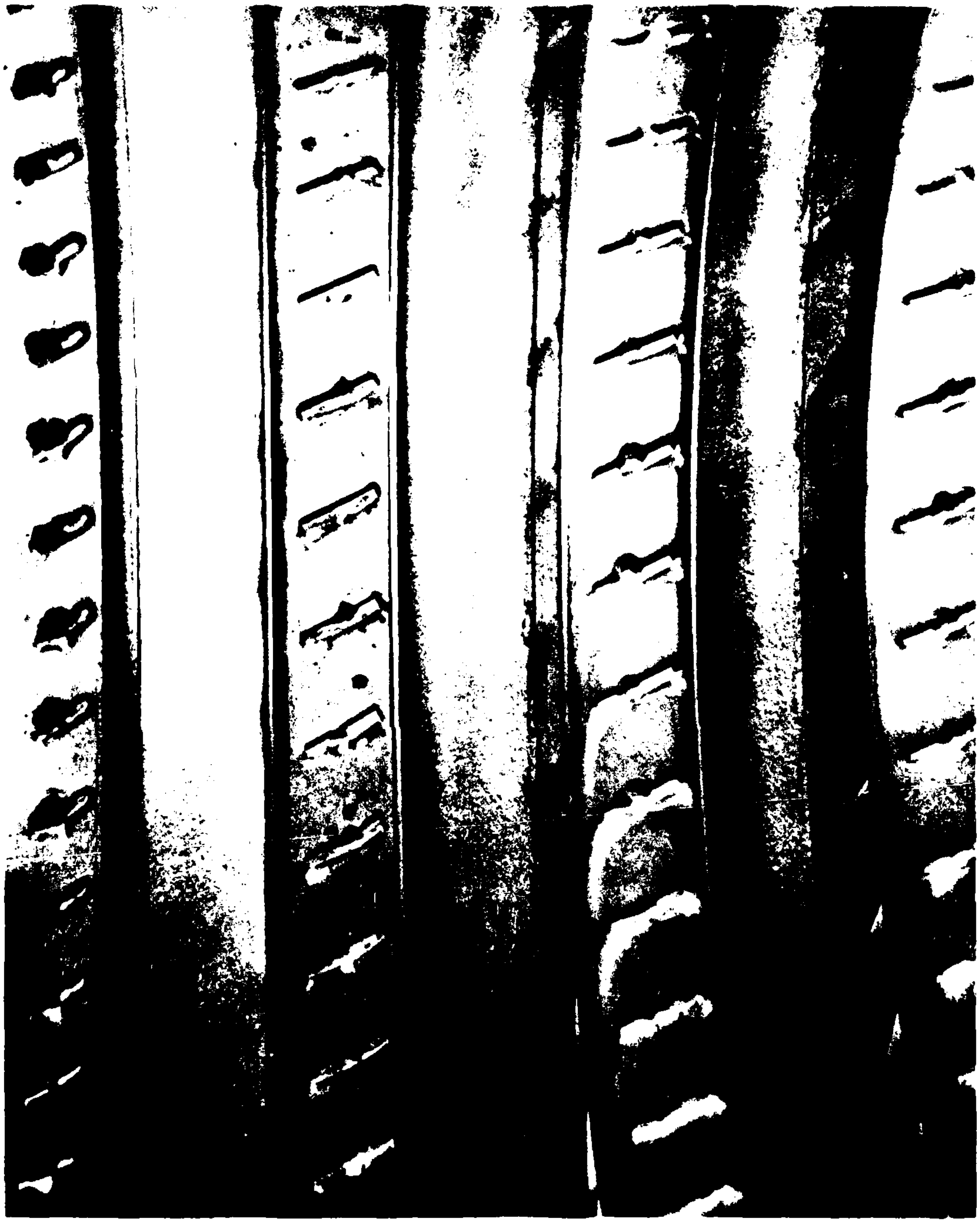
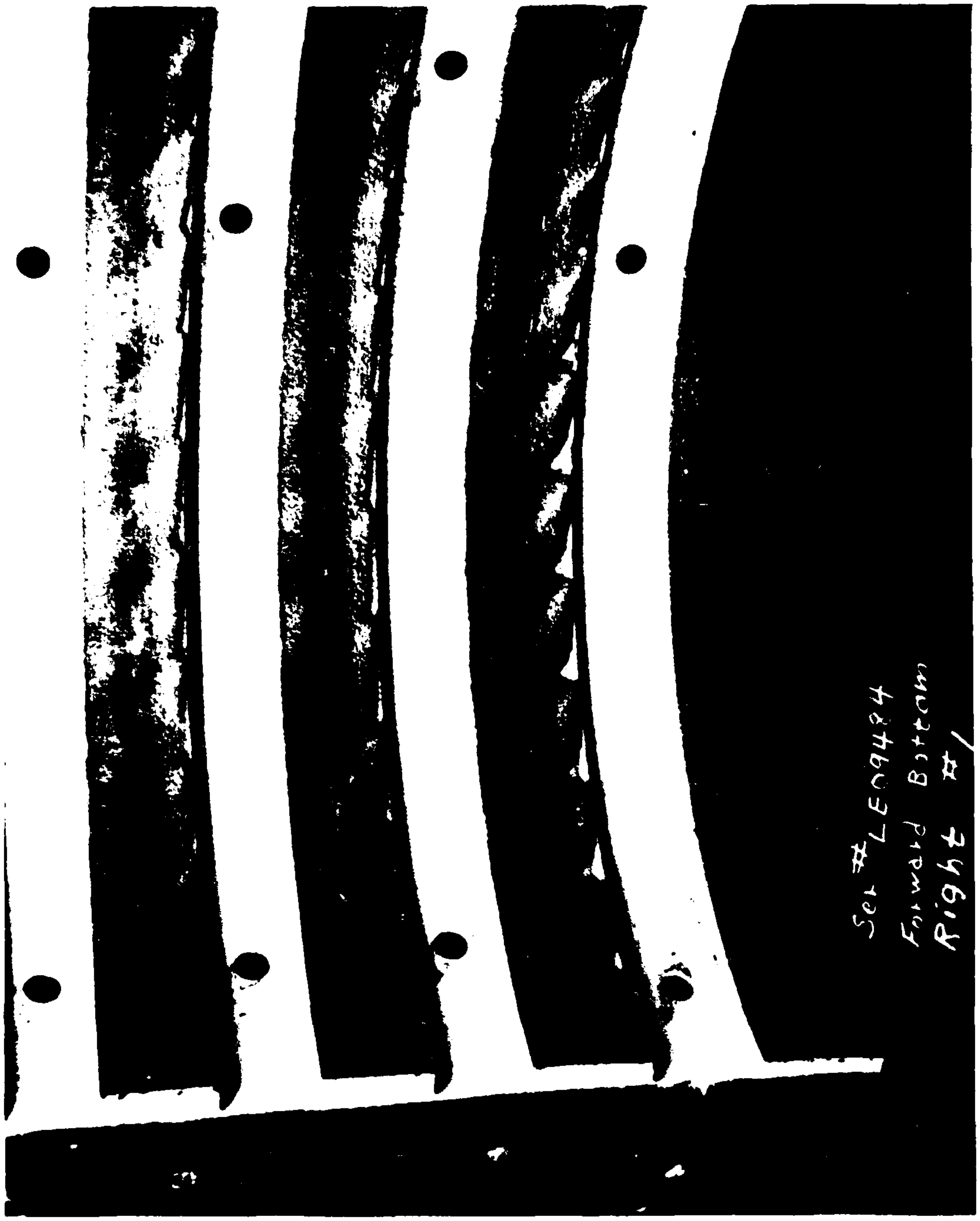


Figure 24.

Figure 25.

Figure 26.

Figure 27.



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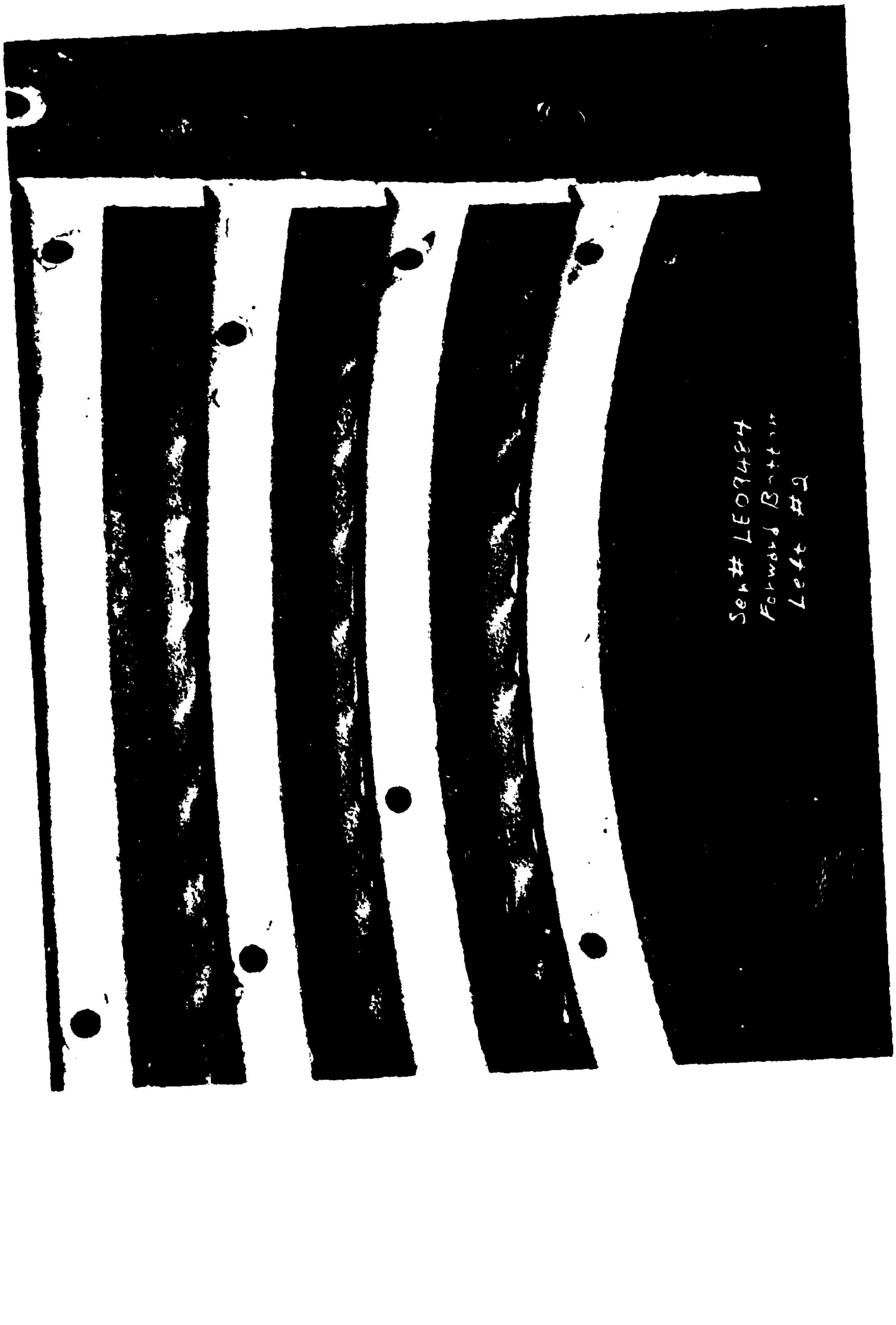

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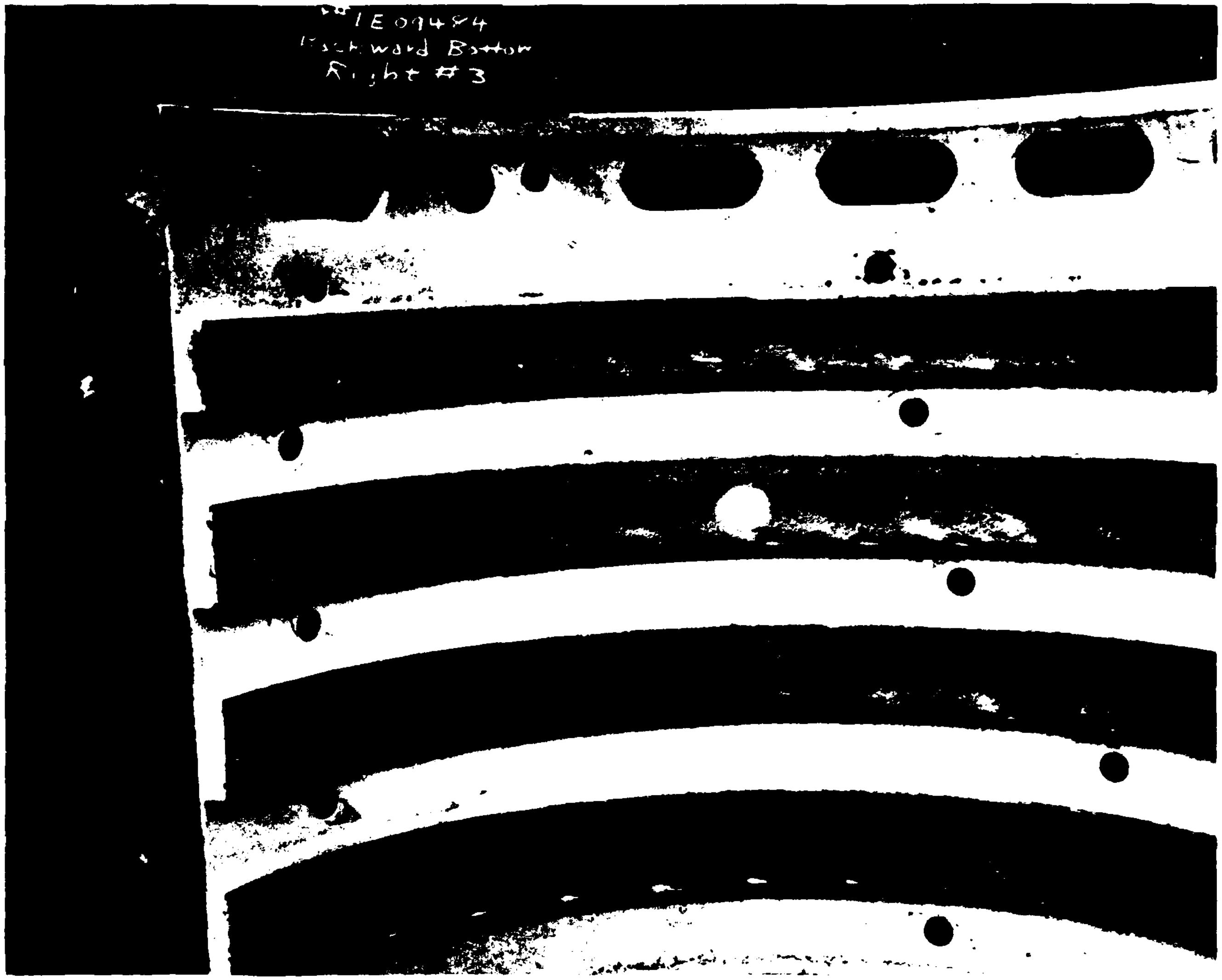

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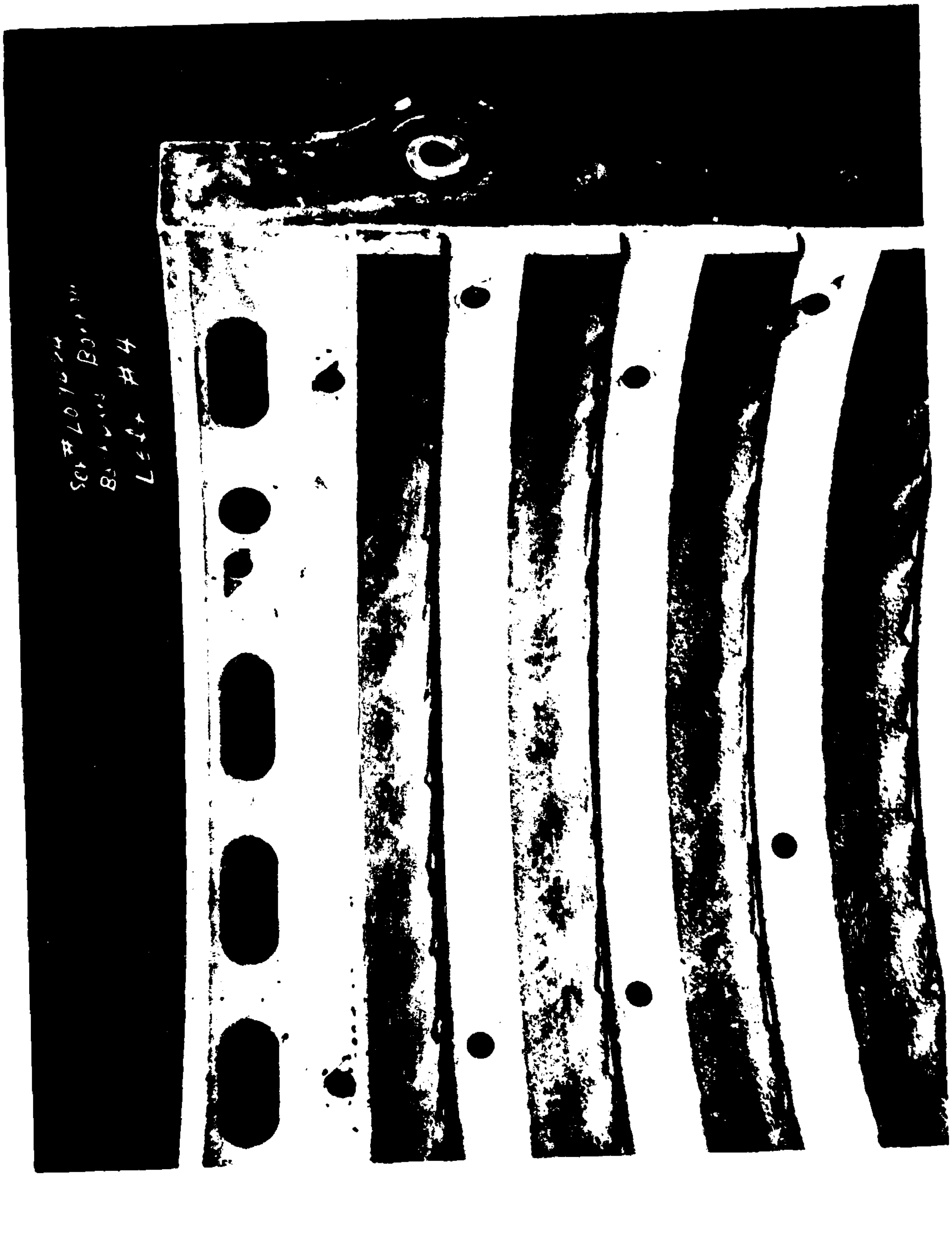

Figure 51.

Figure 32.

Figure [illegible]

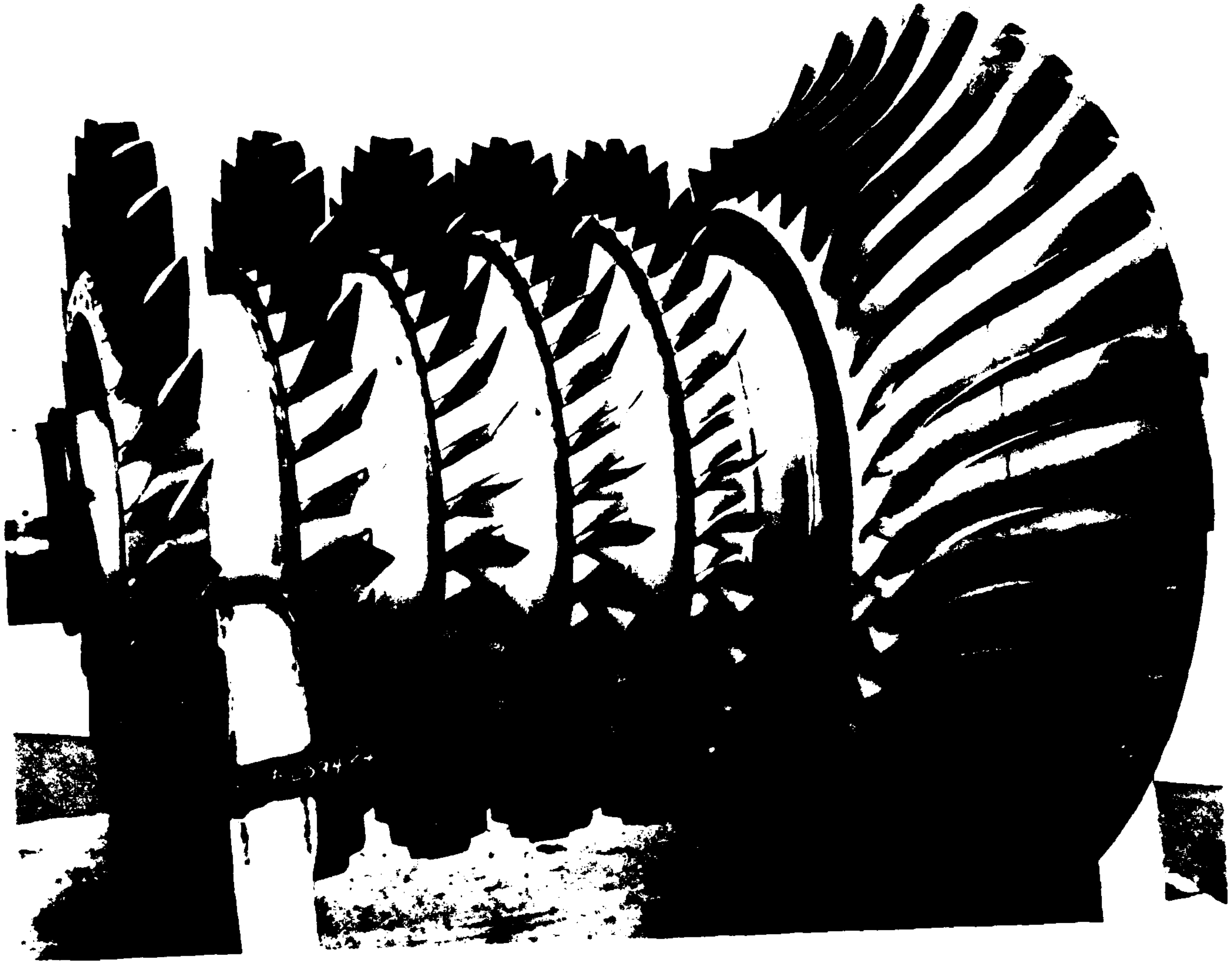

Figure 54.

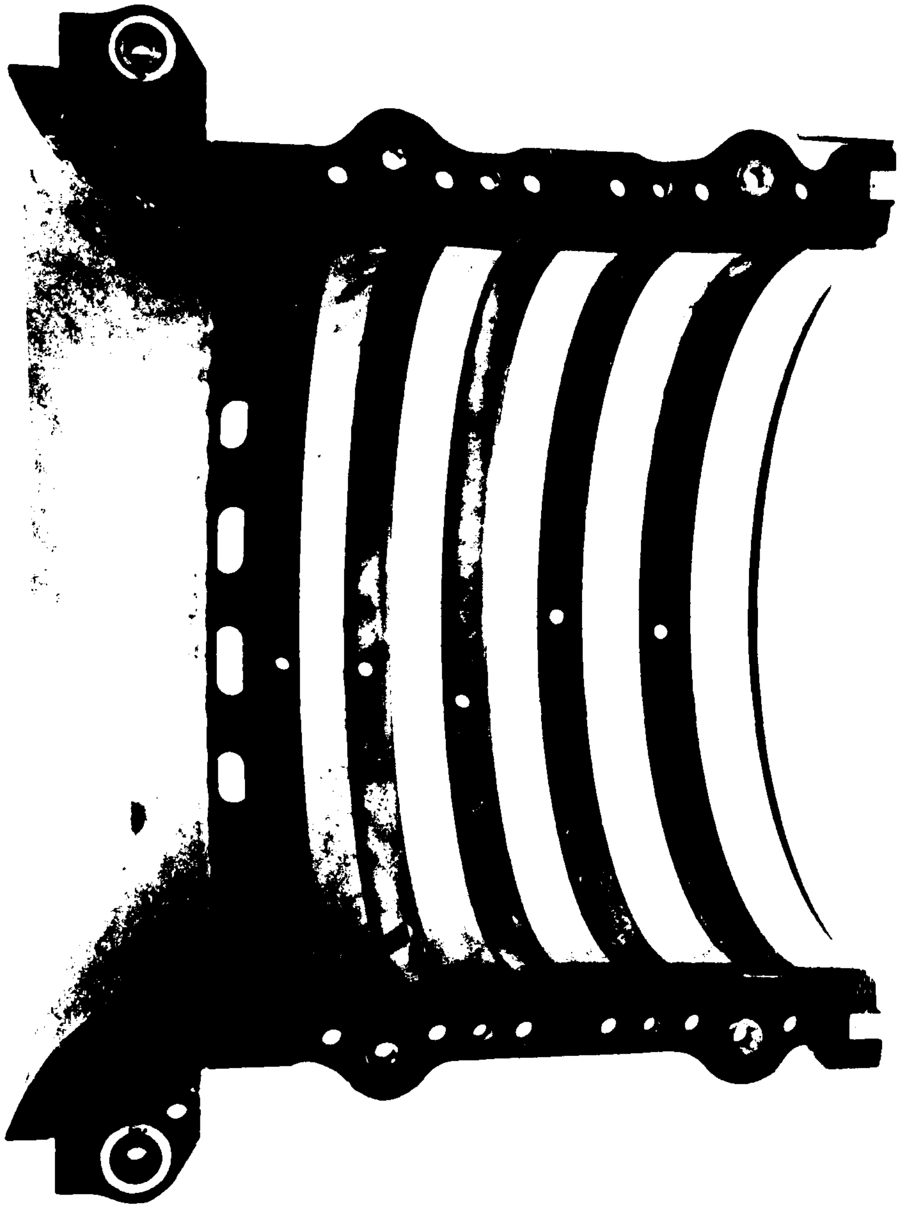

Figure 35.

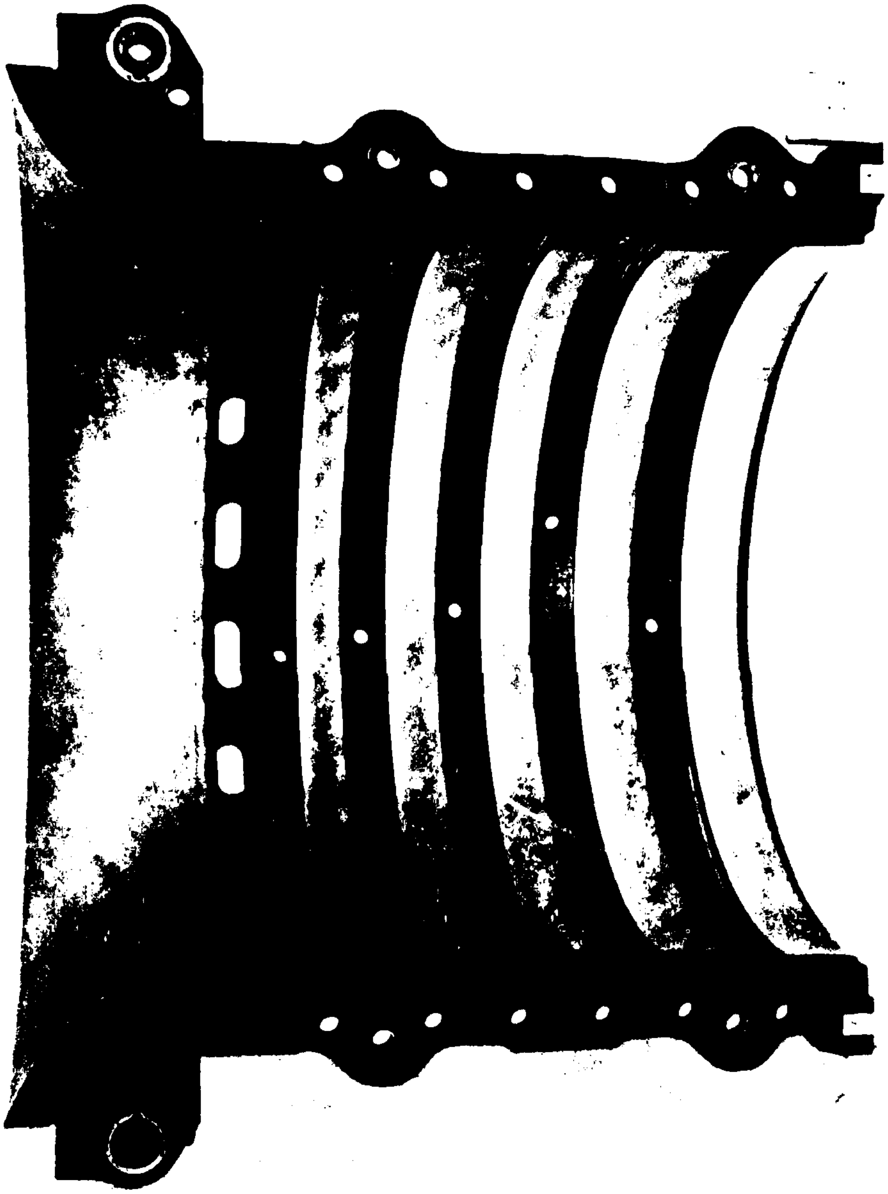

Figure 36.

Figure [illegible]

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ABSTRACT

1. Without the dimensional data on component parts of the compressor, prior to test, there is no accurate yardstick to measure the severity of the test. Likewise, there is no basis (available to this writer) to allow computation of expected service life in field erosion environment. Indications are, however, that the erosion environment during the Ft. Rucker test is more severe than the erosion environment experienced by the average engine returning from R. V. N.

2. Assuming that the impeller, compressor blades and stator vanes were new or like new prior to test, then this would indicate that the metal spray repaired housing would have a life expectancy greater than that of a new magnesium housing, when operated in an erosion environment.

3. Under this severe testing, the metal spray coating in the axial compressor housing showed no signs of bond failure. This further compliments the integrity of the coating system.

4. There were no signs of corrosion anywhere in the housing. However, the Ft. Rucker test was mainly concerned with erosion. There was no corrosion testing done to this writer's knowledge.

5. This writer feels that the Ft. Rucker test has further substantiated the integrity of the metal spray repair procedure. However, the stainless steel insert repair procedure is superior in quality. Due to further developments within ARADMAC the stainless steel insert repair procedure has also become the more economically desired process.

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III	PHOTO OF CENTRIFUGAL COMPRESSOR HOUSING
IV	PHOTO OF COMPRESSOR BLADES
V	PHOTO OF IMPELLER VANES
VI	PHOTO OF STATOR VANES (FWD SIDE)
VII	PHOTO OF STATOR VANES (AFT SIDE)

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PURPOSE

The purpose of this report is to provide this writer's evaluation of the metal spray repaired axial compressor housing (S/N P241A) which has undergone environmental testing at Ft. Rucker.

SECTION II

BACKGROUND

1. The T53-L-11 test engine (S/N LEO 9484) was chosen at random from a group of engines having completed overhaul at ARADMAC on 2 Nov 66. This test was directed by AMC, the purpose of which was to further evaluate the metal spray repaired axial compressor housing (S/N P241A) used on engine LEO 9484. Data is not available to show whether the compressor blades, stator vanes and centrifugal impeller were new or used parts. However, the erosion limits for the compressor blades at that time were very [illegible], allowing use of only those blades which were "like new."

2. The metal spray repaired axial compressor housing (P241A) was repaired under an early repair spec. (SEO T53L0-I0058). The metal spray thickness on subject housing was .045 to .050 inch. The latest metal spray repair specification (SEO T53L0-I0064A) provides a method of processing which minimizes distortion, along with an improved system [illegible] corrosion resistance.

SECTION III

ENGINE TEST

1. The test engine was installed in a helicopter at Ft. Rucker for endurance testing. The endurance test lasts for 200 flying hours, one minute of each hour is spent in the Ft. Rucker sand pit for accelerated erosion aging.

2. The test engine completed 174 hours and 50 minutes of testing (3 hours and 25 minutes of which was in the Ft. Rucker sand pit), at which time the engine was removed for surge and internal damage. The internal damage being visual erosion damage in the compressor section of the engine.

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3. The test engine was returned to ARADMAC early in Feb 67, at which time it underwent performance testing. The performance test was monitored by Mr. A. Schrier of ARADMAC. A copy of Mr. Schrier's report is attached. (Incl 1). It should be noted that a degradation of performance has occurred, which is to be expected, however, the surge reported by Ft. Rucker could not be duplicated in the ARADMAC test cell.

SECTION IV

DISASSEMBLY INSPECTION

1. Axial Compressor Housing S/N P241A (See Inclosure II).

a. Erosion damage is more severe on the bottom half of the housing than on the top half. This indicates that the greater concentration of sand and dust enters the engine at approximately the 6 o'clock position.

b. The greatest erosion damage was realized on the second stage land (bottom of housing) in which 12 of the 18 "SWIRL" patterns show erosion thru the bronze coating and into the base metal. There is no other area of the housing showing erosion thru the coating system, including the 2nd stage land in the top half of housing. Nine of the twelve "SWIRL" patterns, which are eroded thru the coating, are between the 3 o'clock and the 6 o'clock position (as looking upstream). The erosion damage progressively gets more severe from the 6 o'clock position to the 3:45 o'clock position, on second stage land, where it is the most severe. From the 3:45 o'clock position damage quickly decreases and becomes almost constant around the top half of the housing. The "erode thru" areas are just aft of the leading edge and in all cases are surrounded by metal spr. . (The leading edge of the land is "shadowed" and thus is protected by the aft edge of the stator vane outer shroud.) The pattern of the "eroded thru" area at the bottom of the more advanced or deeper "SWIRL" patterns is shaped like the profile of a wave (see Figure 1), the base of which is parallel to, and just aft of, the leading edge of the land. The largest area of "ERODE THRU" naturally in the deepest SWIRL pattern, which is located only 2 inches down from the split flange (3:45 o'clock position as looking up stream). The width of this "wave profile," at its base, is approximately .330 inch, and the height is approximately .175 inch. The depth of this swivel pattern is .065 inch below drawing dimensions.

c. The erosion damage on all lands seems to be concentrated on the forward half of the land surface. See Figure 2 for complete outline of erosion pattern with dimensional data.

d. There are indications that the erosion mechanism starts by eroding out a small thin chip of metal spray just aft of the leading edge of the land. After the chip is removed, the erosion mechanism continues by picking out particles (which would be similar in effect to sanding) and the now common "SWIRL" pattern is thus formed. There is no evidence of compressor damage from the small initial metal spray chips, which indicates immediate fragmentation upon first impact with a compressor rotor blade. This conclusion is substantiated, to a degree, by examining the porous, laminated structure of the bronze metal spray, which would lend to fragmentation upon impact.

NOTE

> The chip of metal spray, referred to above, is a small thin shell of material removed from the surface of the metal spray coating, and is not the result of a metal spray to base metal bond failure.

e. There is no indication of metal spray bond failure or corrison attack on this test housing.

2. Centrifugal Compressor Housing S/N XR9192 (See Incl III).

a. This housing was either new or like new, to have met assembly requirements during overhaul of test engine in Nov 66.

b. See Figure 3 for dimensional data. It is interesting to note that the top half realized greater erosion damage than did the bottom half of the housing. The extreme erosion damage on this housing further attests to the severity of the Ft. Rucker test. This test housing (S/N XR9192) shall be used as a basis for comparison in future tests of this nature.

3. Compressor Rotor Blades.

a. For dimensional criteria on compressor blades removed from the test engine, see Figure 4.

NOTE

> To attempt reclamation of blades, an additional .010 (approx.) material removal is required to reshape the leading edge of airfoil.

b. As previously stated, there is no data available to indicate whether the compressor blades were new or used at time of engine overhaul in Nov 66. However, erosion limits used by the ARADMAC shops at that time required a "like new" condition.

c. See Incl IV for erosion damage at trailing edge of blade, this damage is not reflected by dimensions shown in Figure 4. This damage is quite severe and eliminates attempts at reclamation on many of the blades.

4. Centrifugal Impeller Vanes.

a. See Figure 5 for dimensional inspection of impeller vanes after test. As previously stated, this writer has no data to show whether this impeller was new or used prior to test. Even a new impeller would have required dimensional data, prior to test, to allow for accumulation of usable data after test.

b. As shown in inclosure V the impeller vanes are severely eroded.

5. Stator Vanes:

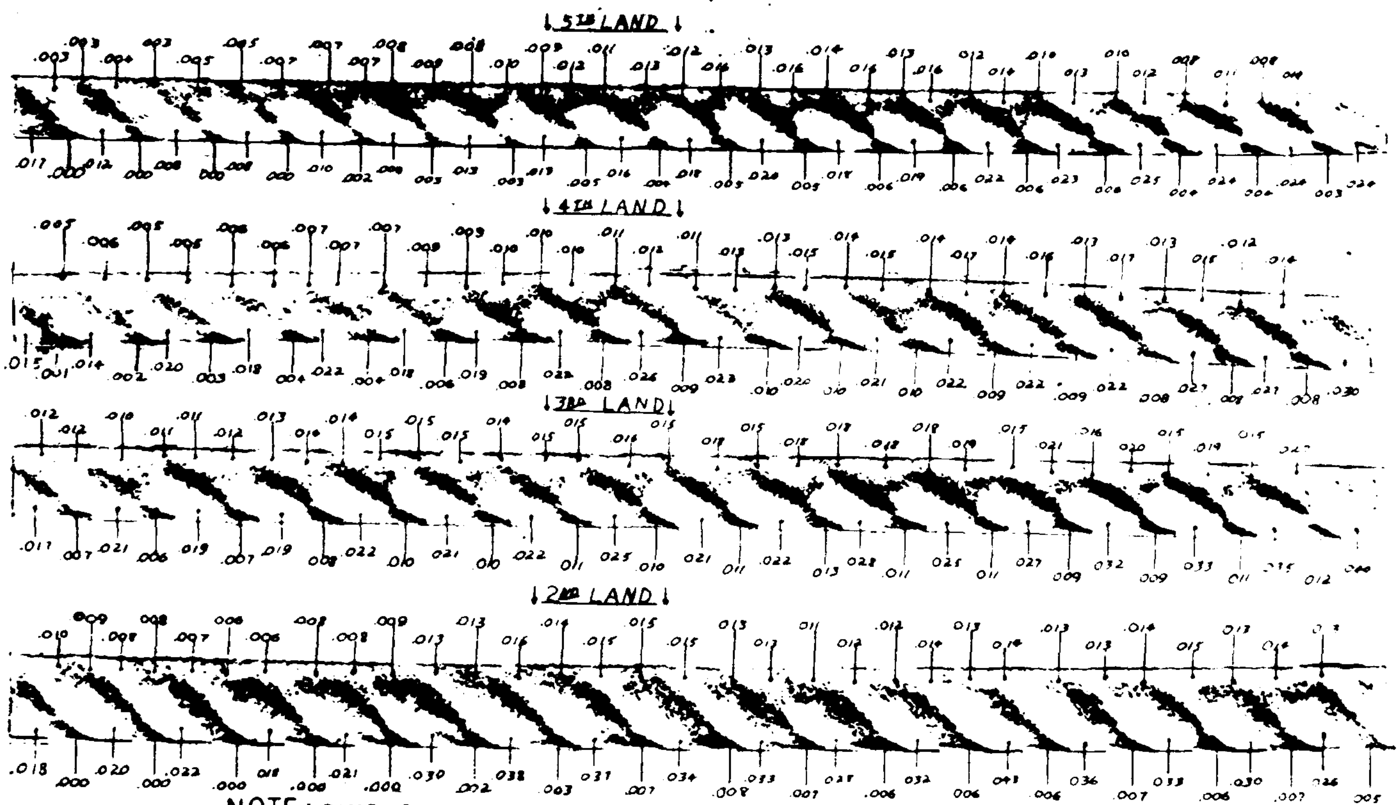
a. See inclosures VI thru XII which show the severe erosion damage on subject stator vanes. There is no criteria available to show whether these impeller vanes were new or used parts at time of test engine overhaul in Nov 66. Dimensional inspection has been accomplished after test. Should this data be desired, contact this writer.

6. N1 Turbine Nozzle:

a. The N1 turbine nozzle had two (2) burned vanes (See Inclosure XIII). This damage is sufficient to cause a noticeable degradation of performance. By replacing this turbine nozzle there is a strong possibility that this engine could have maintained overhaul test performance requirements. However, there is also the possibility that "tweeking" the engine in the field to make up for loss in performance caused by compressor erosion damage, has caused the higher than normal temperature that burned the vanes in question.

The above impression of the second stage land shows typical "swirl" patterns caused by sand and dust erosion. The dark areas are the peaks (high spots) and the light areas are the valleys (low spots). One "erode thru" area was drawn in to show the shape and location, and also the point of deepest erosion.

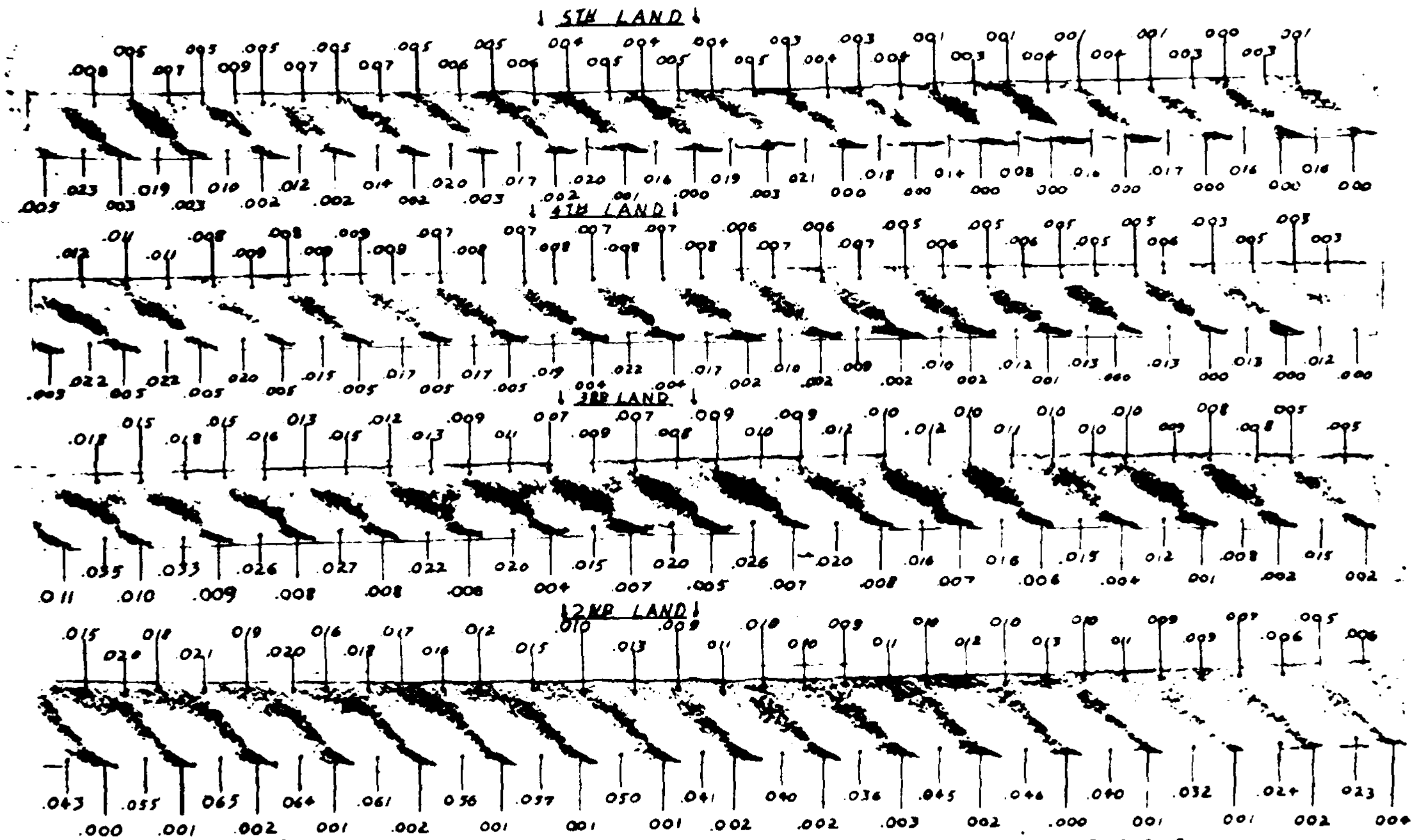
FIGURE 1



NOTE: DIMENSIONS SHOW EXTENT OF EROSION BELOW DRAWING DIMENSIONS

FIGURE 2 (SHEET 1)

IMPRESSIONS OF SECOND THROUGH FIFTH LANDS TO SHOW EROSION DAMAGE
TOP HALF OF AXIAL COMPRESSOR HSG.



NOTE: DIMENSIONS SHOW EXTENT OF EROSION BELOW DRAWING DIMENSIONS

FIGURE 2 (SHEET 2)

IMPRESSIONS OF SECOND THROUGH FIFTH LANDS TO SHOW EROSION DAMAGE
BOTTOM HALF OF AXIAL COMPRESSOR HSG.

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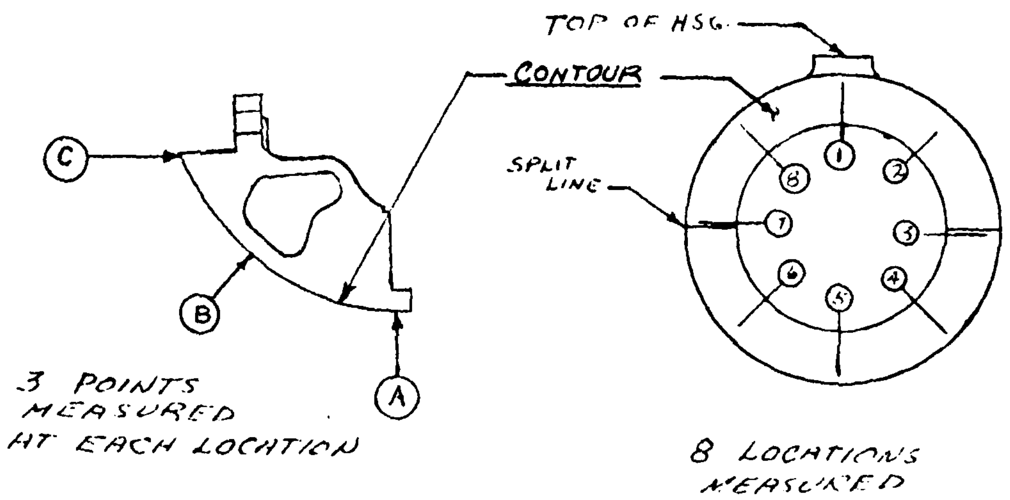
FORT RUCKER TEST ENGINE
CENTRIFUGAL COMPRESSOR HOUSING

The below listed data concerns the measurement of the centrifugal compressor housing contour for erosion damage. Dimensions listed show extent of erosion below drawing minimum.



INSPECTION POINTS	LOCATIONS							
	1	2	3	4	5	6	7	8
A	-.005	-	-.008	-	-.005	-	-.008	-
B	-.014	-.012	-.010	-.002	-.007	-.001	-.005	-.011
C	-.026	-.022	-.020	-.008	-.019	-.007	-.025	-.028

Figure 3

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FORT RUCKER TEST ENGINE
COMPRESSOR ROTOR BLADES

The below listed data concerns chord width measurements of compressor blades as an inspection for erosion damage. Chord width measurements are taken at the locations specified below for each blade.

a. 1st stage blade - 1/2 inch from blade tip

b. 2nd stage blade - 3/8 inch from blade tip

c. 3rd stage blade - 3/8 inch from blade tip

d. 4th stage blade - 1/4 inch from blade tip

e. 5th stage blade - 1/4 inch from blade tip

Blade Stage	Drawing Dimensions	Avg. Dim. of New Blade (As Received)	Dimension of Blades in Ft. Rucker Test Engine (After Test)		
			Min. Dim. Blade	Max. Dim. Blade	Avg. Dim. Per Stage
1st	.905/.885	.900	.845	.862	.856
2nd	.805/.785	.800	.758	.770	.765
3rd	.685/.665	.680	.650	.668	.658
4th	.685/.665	.680	.647	.658	.653
5th	.685/.665	.680	.644	.660	.654

Figure 4

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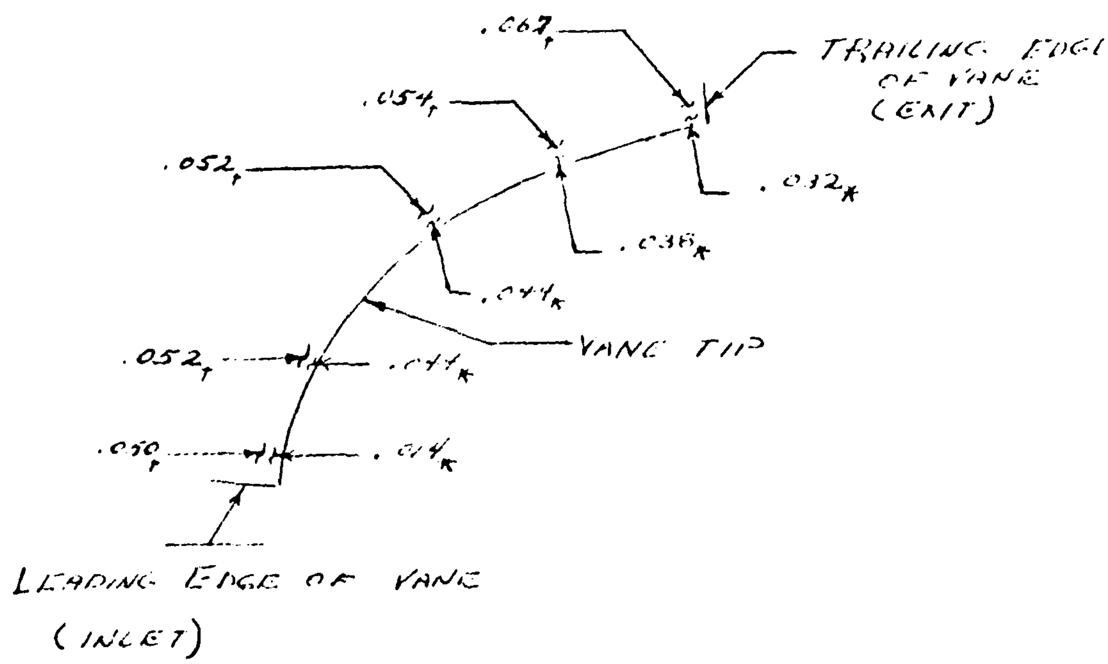
FORT RUCKER TEST ENGINE
CENTRIFUGAL IMPELLER

The below listed data concerns the vane thickness measurement as an inspection for erosion damage. One typical vane was measured five locations equally spaced along the blade length. Two measurements were taken at each location, 1/16 inch from vane tip and 3/8 inch from blade tip respectively.



*Measurement taken 1/16 inch from vane tip
+Measurement taken 3/8 inch from vane tip

Figure 5

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INVESTIGATION ENGINE LE09484

T53L11 Investigation Engine Serial No. LE09484 runs normal at all power settings except for exhaust gas temperature and fuel flow. At normal rated E. G. T. was out of limits 16°F. and fuel flow 23 PPH. At military rated power E. G. T. was out of limits 6°F. and fuel flow 11 PPH. At take off power E. G. T. was out of limits 51°F. and fuel flow 18 PPH.

Acceleration time from G. I. to take off power was .7 seconds slower than allowed by work specifications and E. G. T. was higher than normal but not out of limits.

Acceleration time from F. I. to take off power was .1 second slower than allowed by work specification and E. G. T. was also higher than normal but not out of limits.

For wave off checks, engine could not be stabilized at take off power as prescribed by work specifications because of E. G. T. limit of 1200°F., but was stabilized at a lower speed for the prescribed time before checks were made. Engine performed surge free with 30" H_2O applied to P_1 Bellows. The work specification does not recommend applying more than 30" H_2O pressure to fuel control. E. G. T. was higher than normal but did not exceed limits of over 1400°F. or over 1200°F. for more than 5 seconds.

Take off power reading was taken in short settings so as not to exceed E. G. T. limits. No work was performed on engine except for replacing of "O" rings at western gear box adapter cover and adjusting maximum trim to obtain take off power.

/s/A. Schrier

INCLOSURE I

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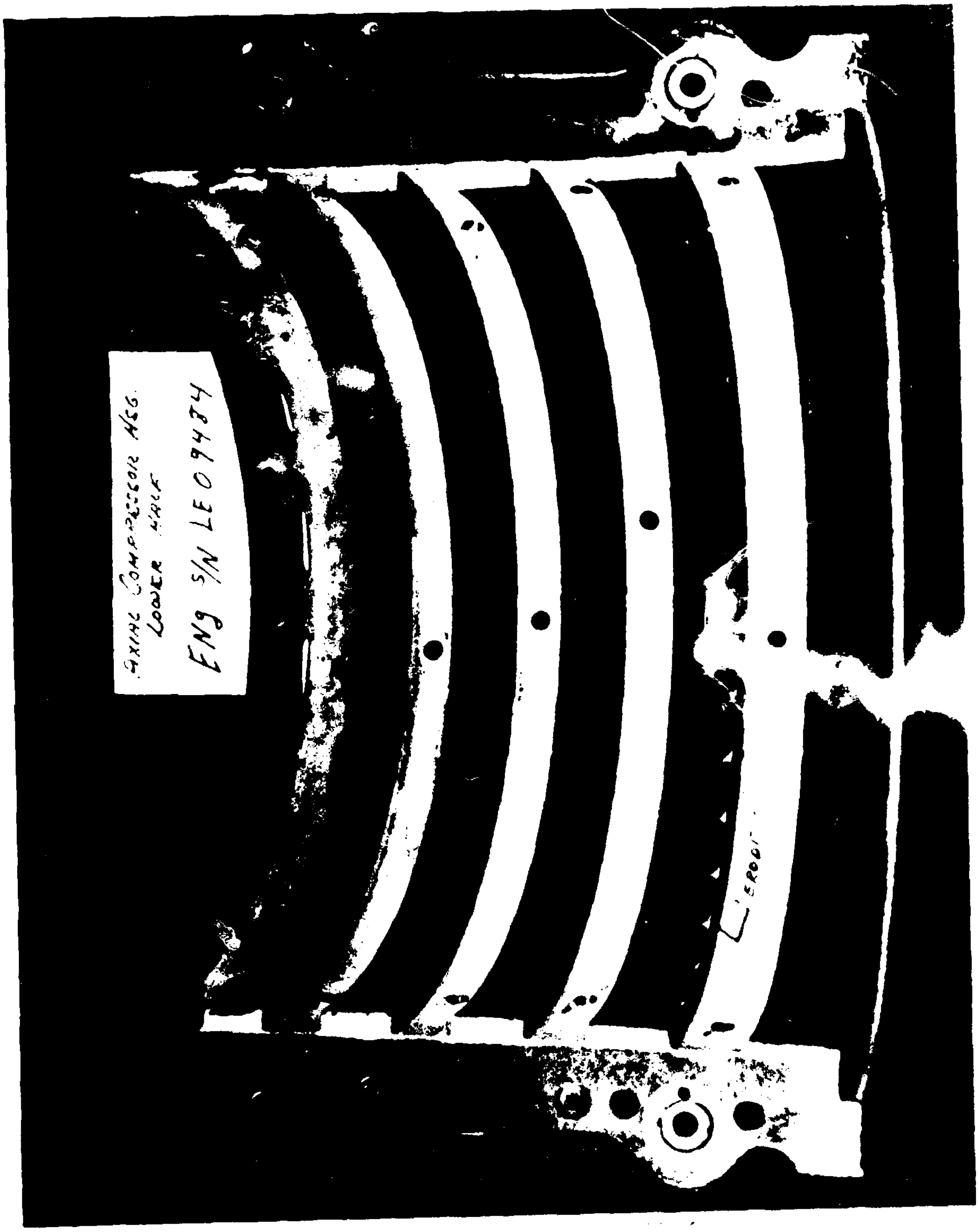
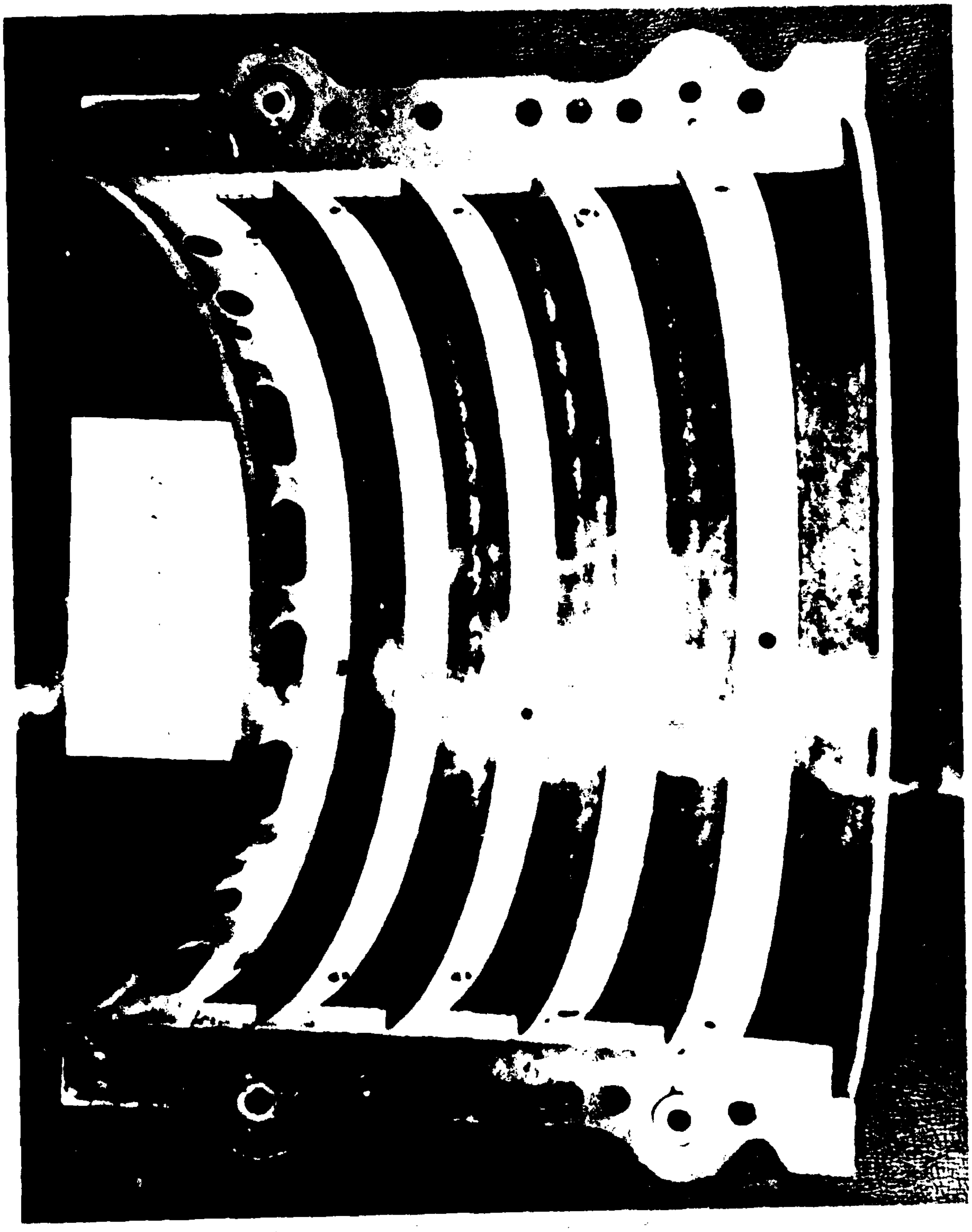
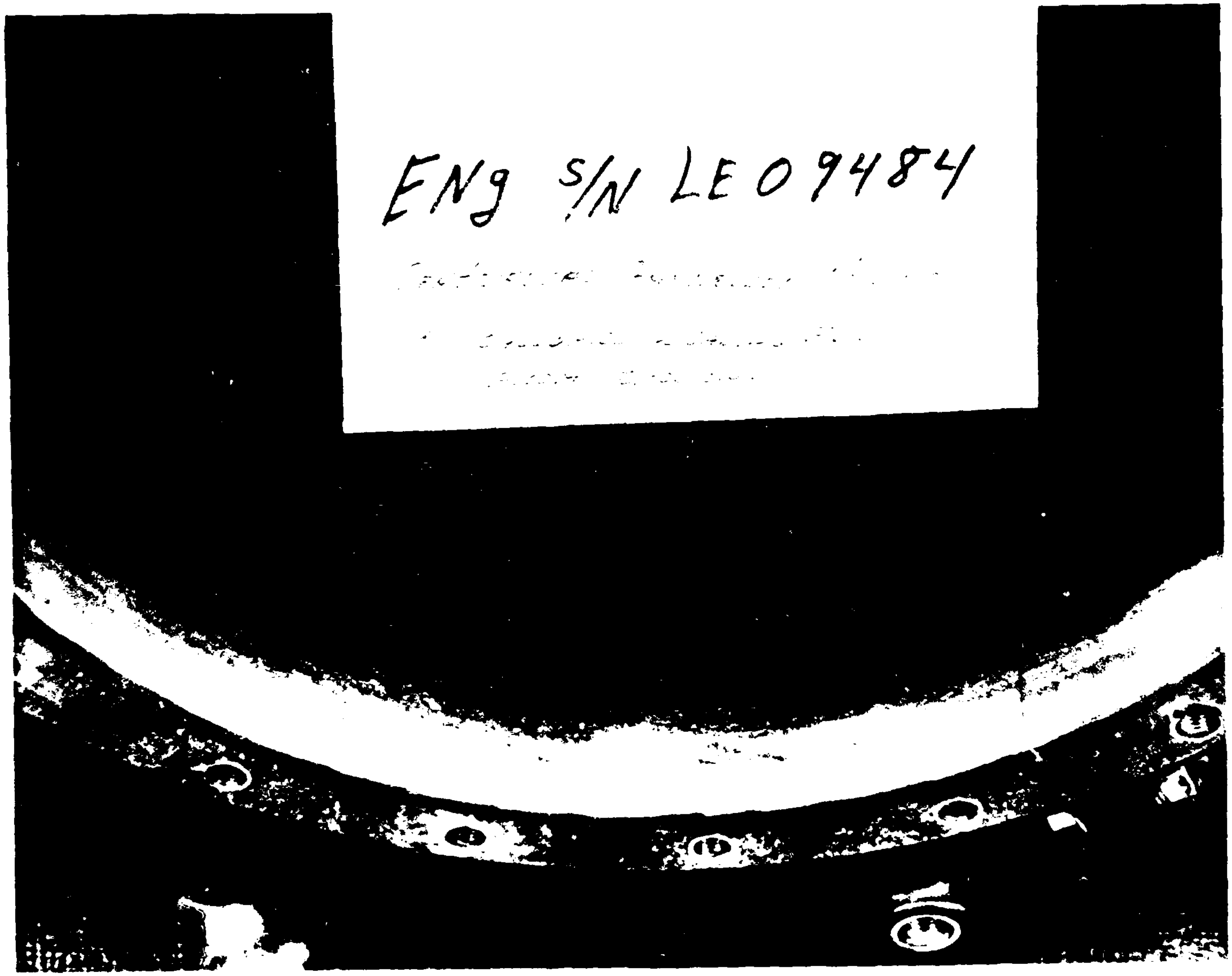
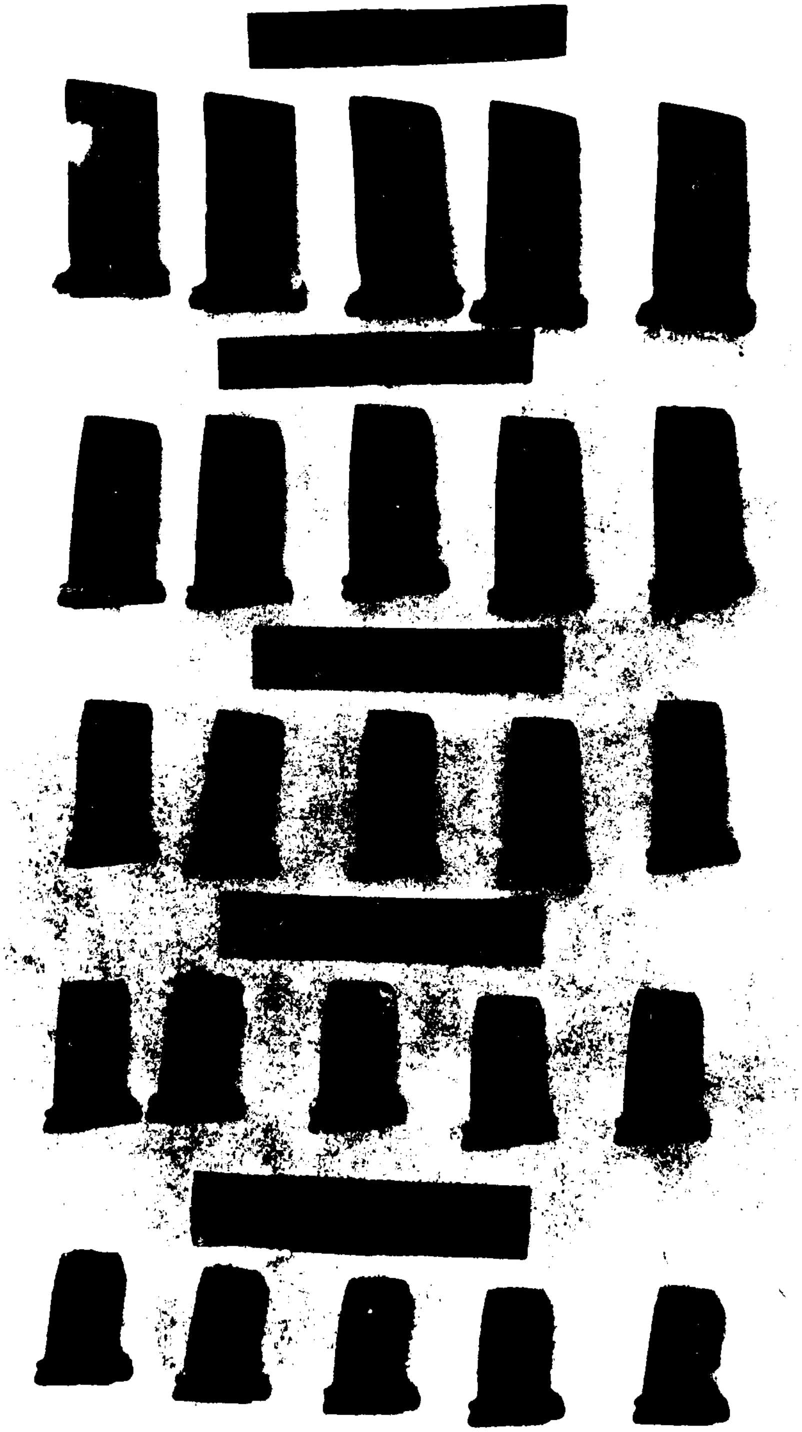
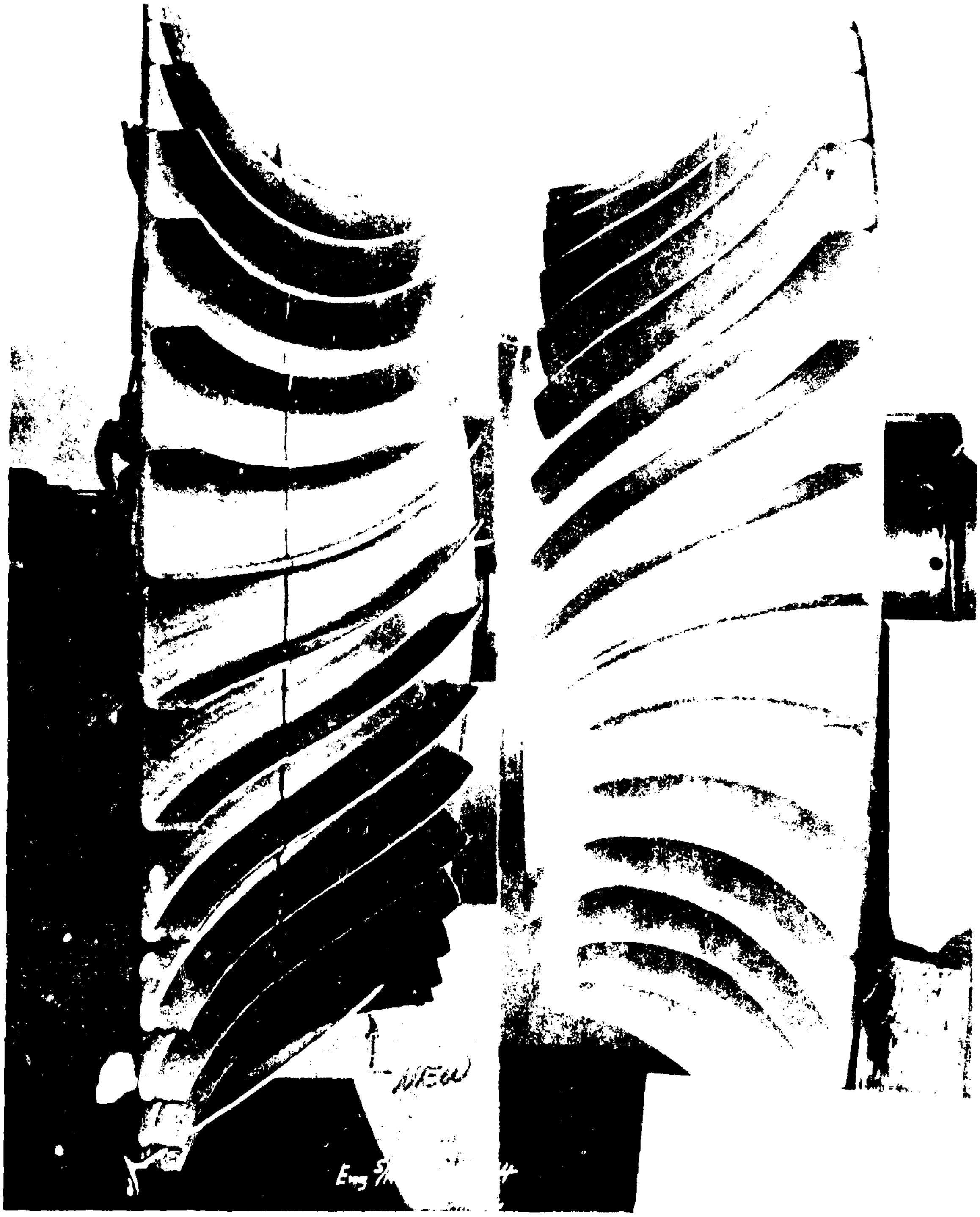

AXIAL COMPRESSOR HSG.
LOWER HALF
ENG S/N LE09484

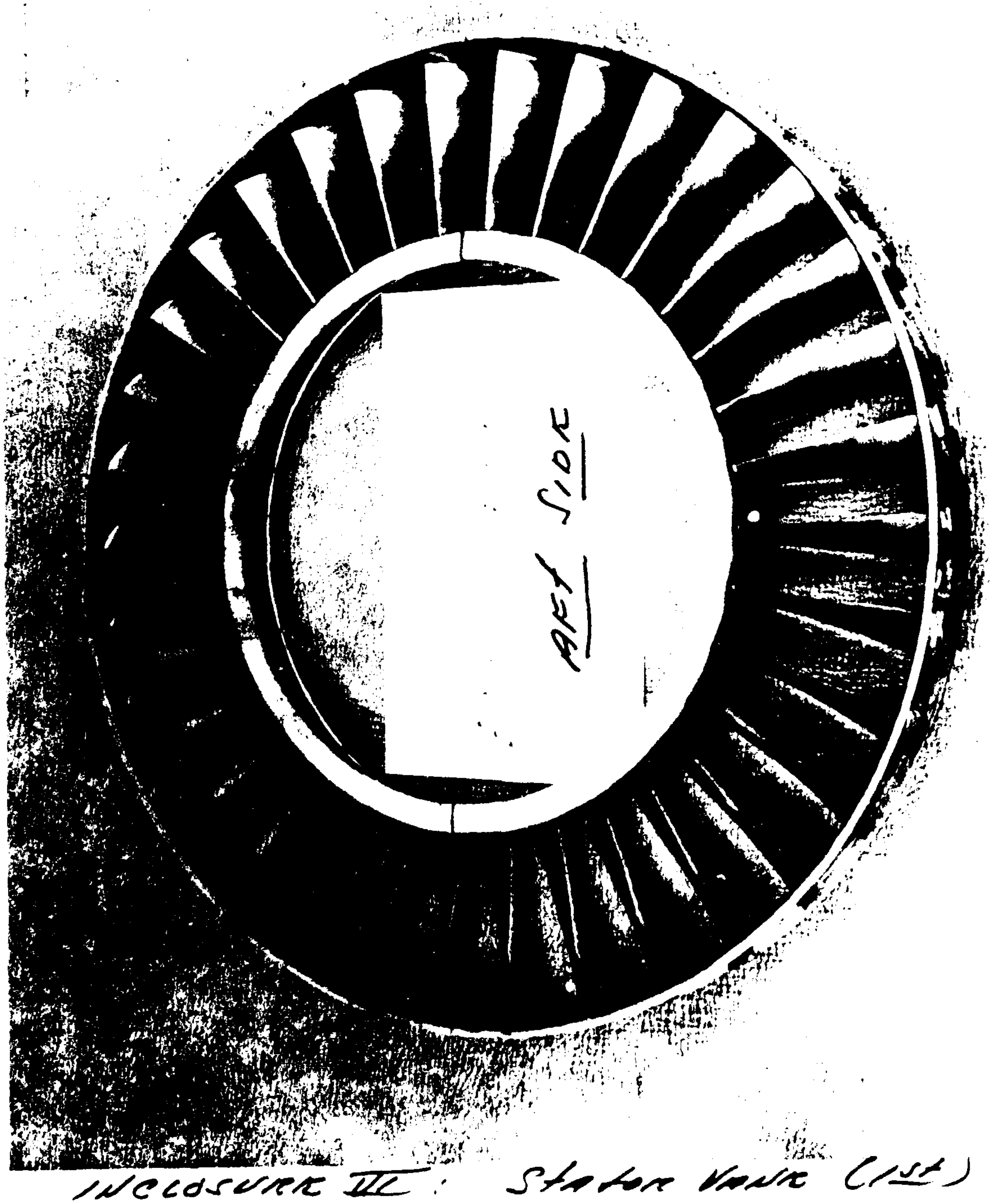



ENg S/N LE09484

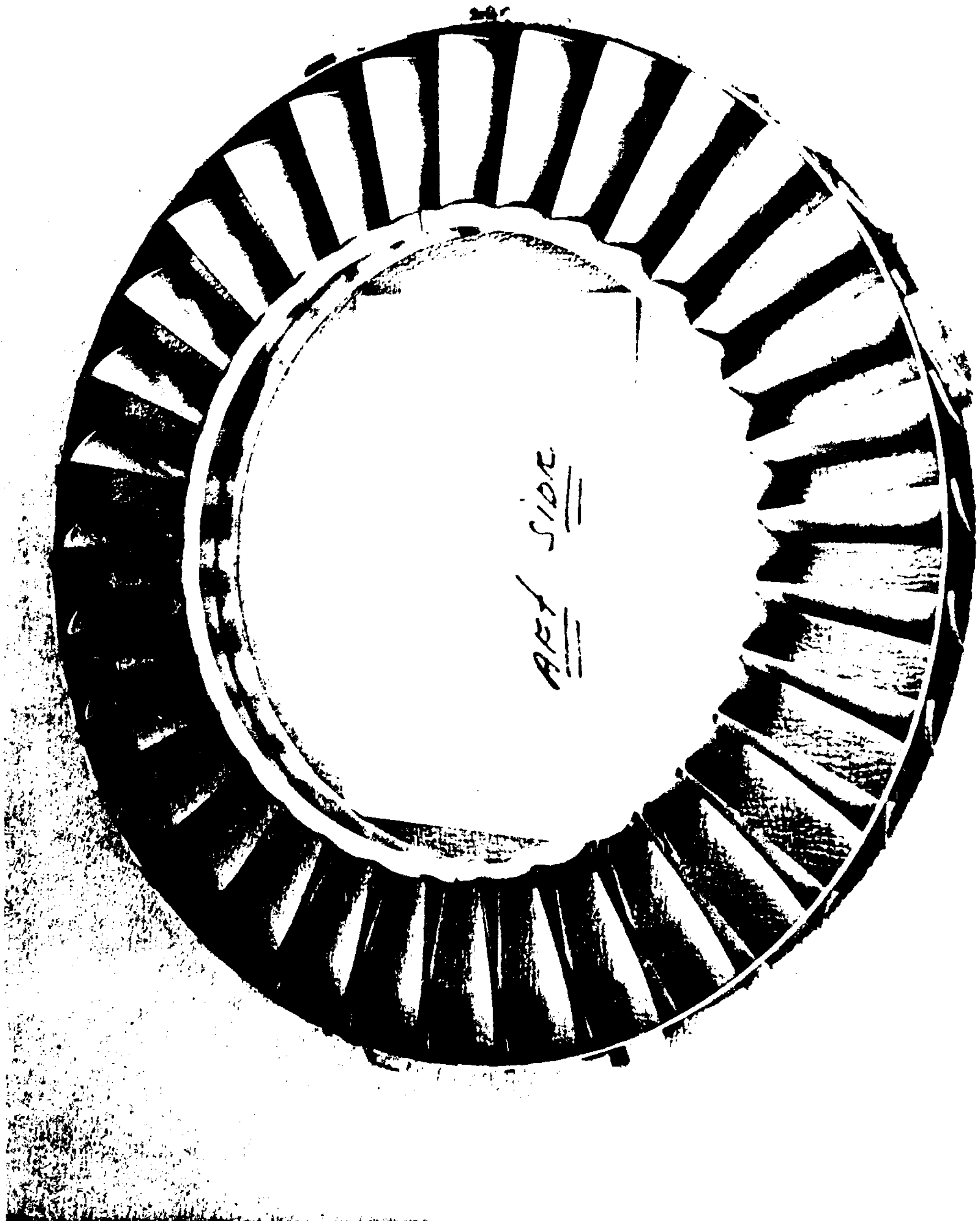


INCLOSURE IV


NEW

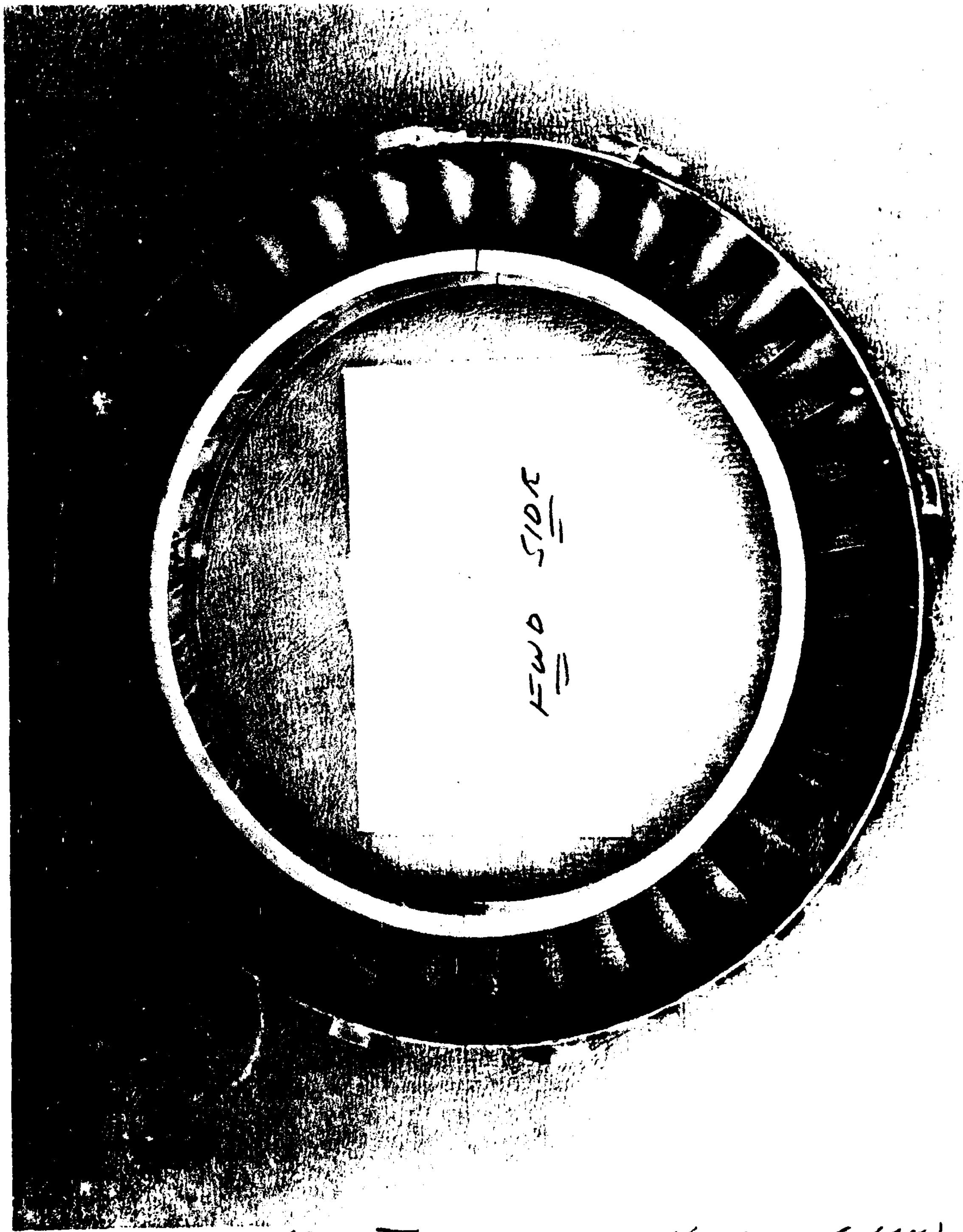


INCLOSURE VI: Stator Vane (1st)

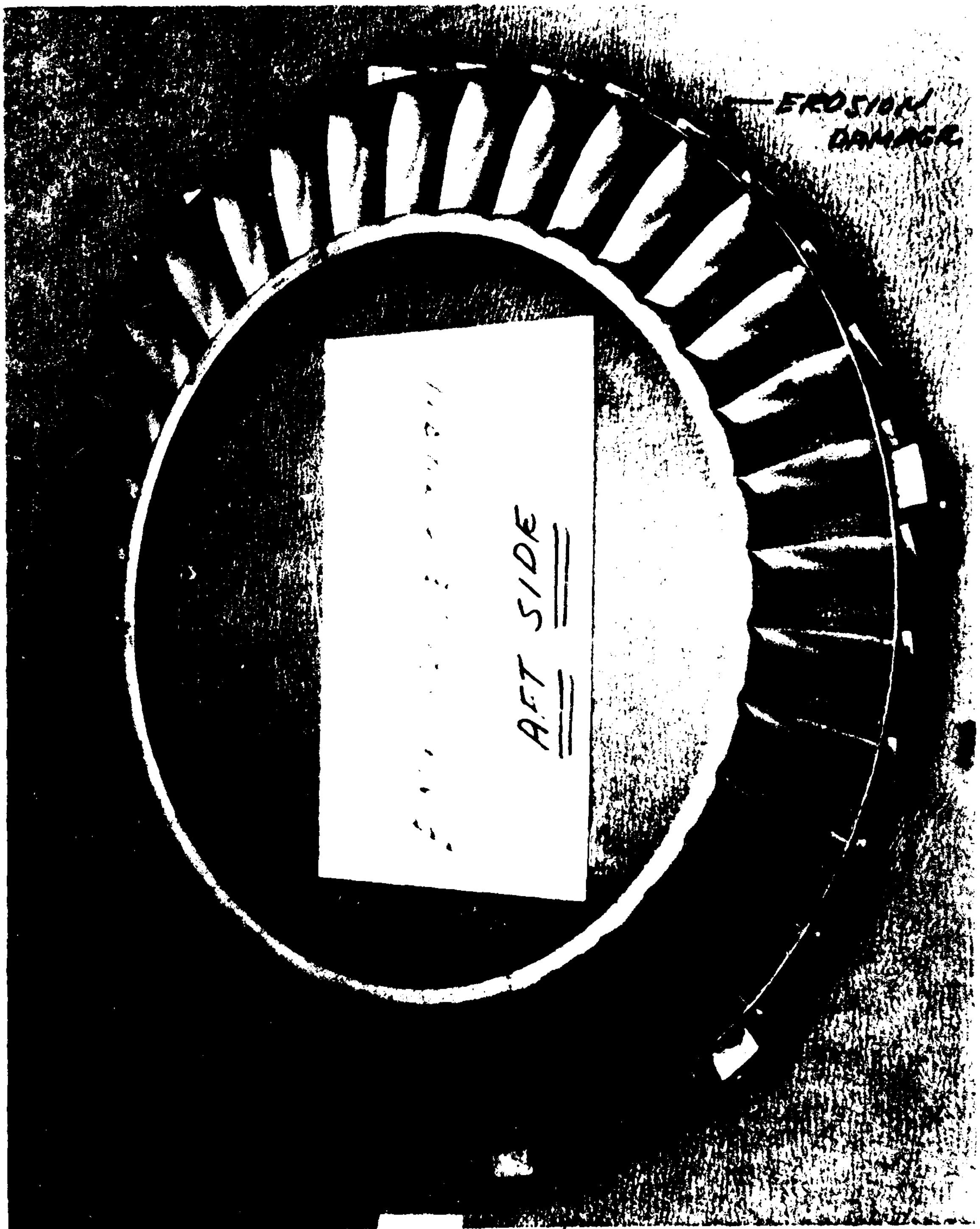


INCLOSURE VIII : STATOR [illegible] (2- [illegible])

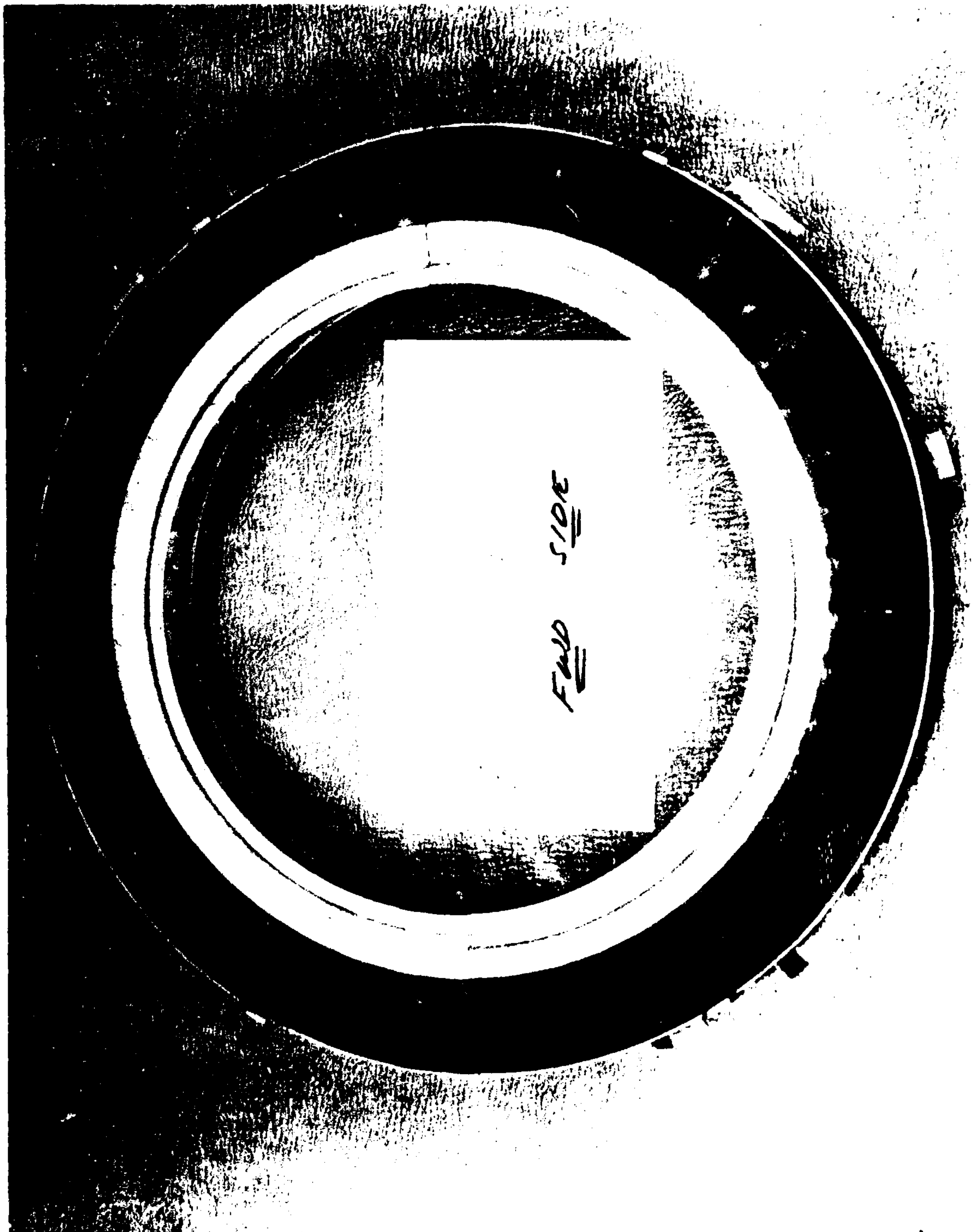
INCLOSURE VIII : STATOR VANE (3RD)



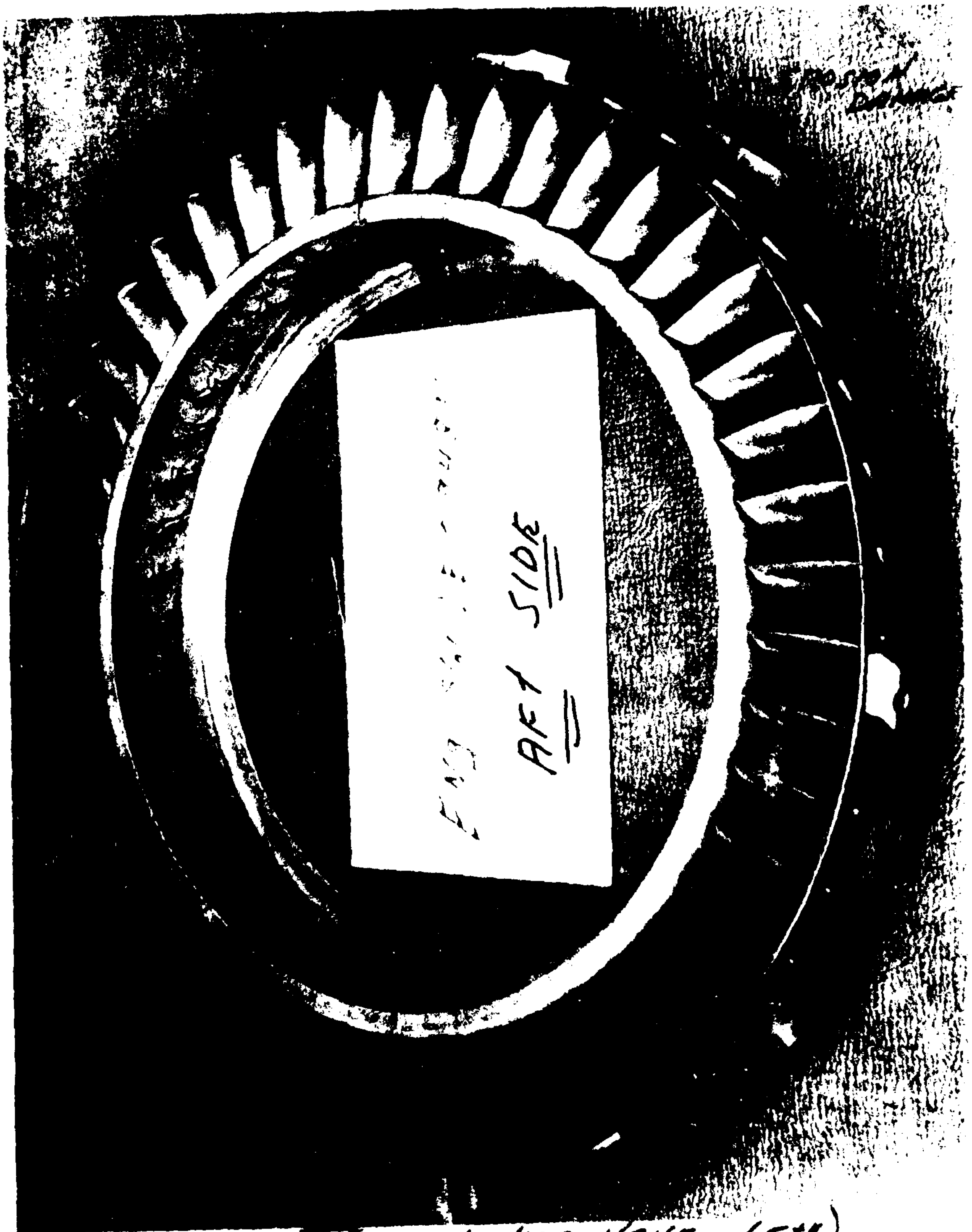
INCLOSURE II: STATOR VANES (4TH)



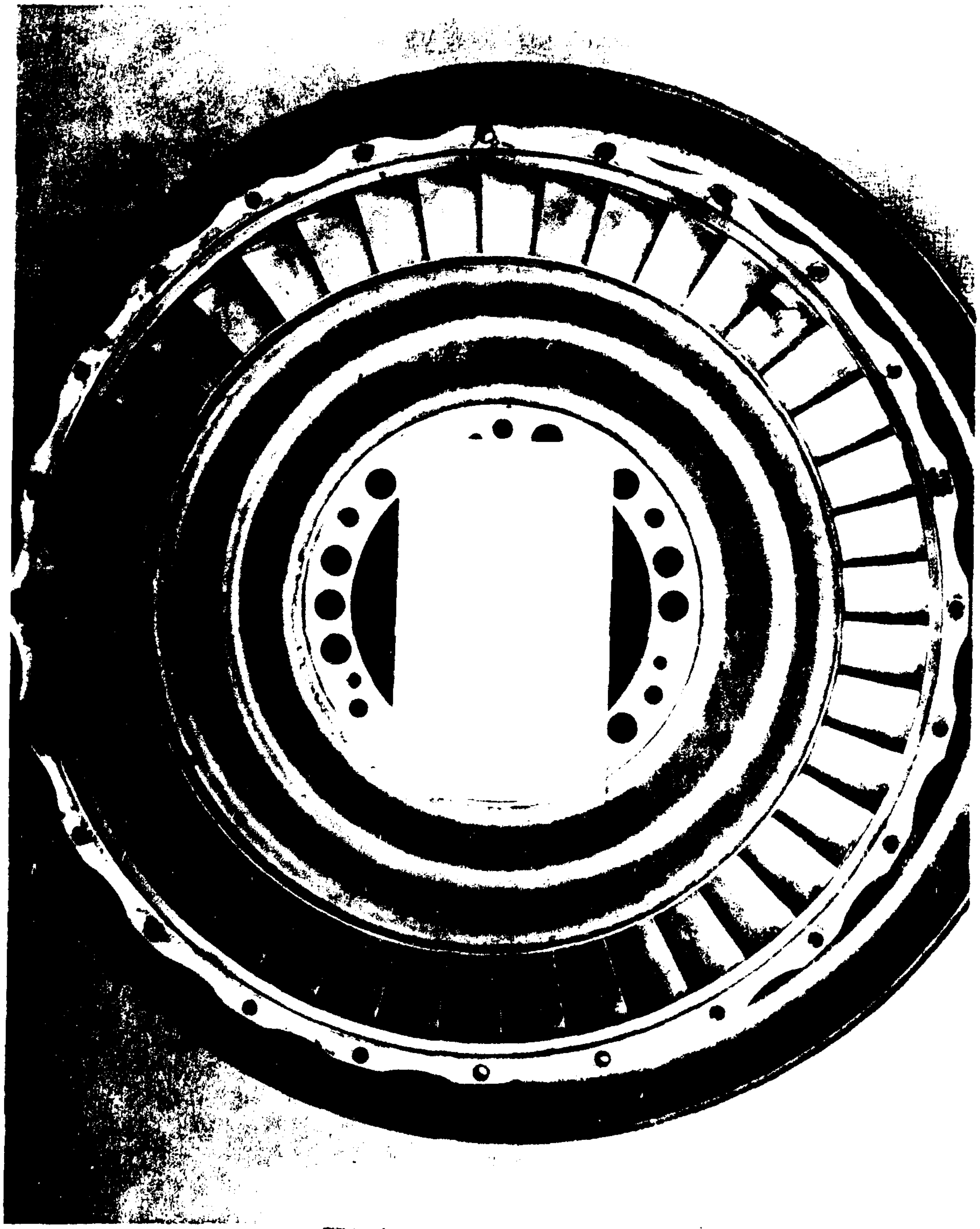
INCLOSURE. I : STATOR VANE (4TH)



ENCLOSURE XI: STATOR VANE (5TH)



INCLOSURE XII: STATOR VANE (5th)



INCLOSURE XIII : N1 TURBINE NOZZLE